TESTING OF PARTIALLY COMPOSITE INSULATED WALL PANELS

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TCA® TILT-UP CONCRETE ASSOCIATION

TILT UP SANDWICH WALL PANEL TEAM

University Team

- Marc Maguire
- Salam Al-Rubaye
- Zach Benson

Contractor

- Steve Miers

Steering Committee

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- Joseph J. Steinbicker
- Philip Kopf

TCA oversight

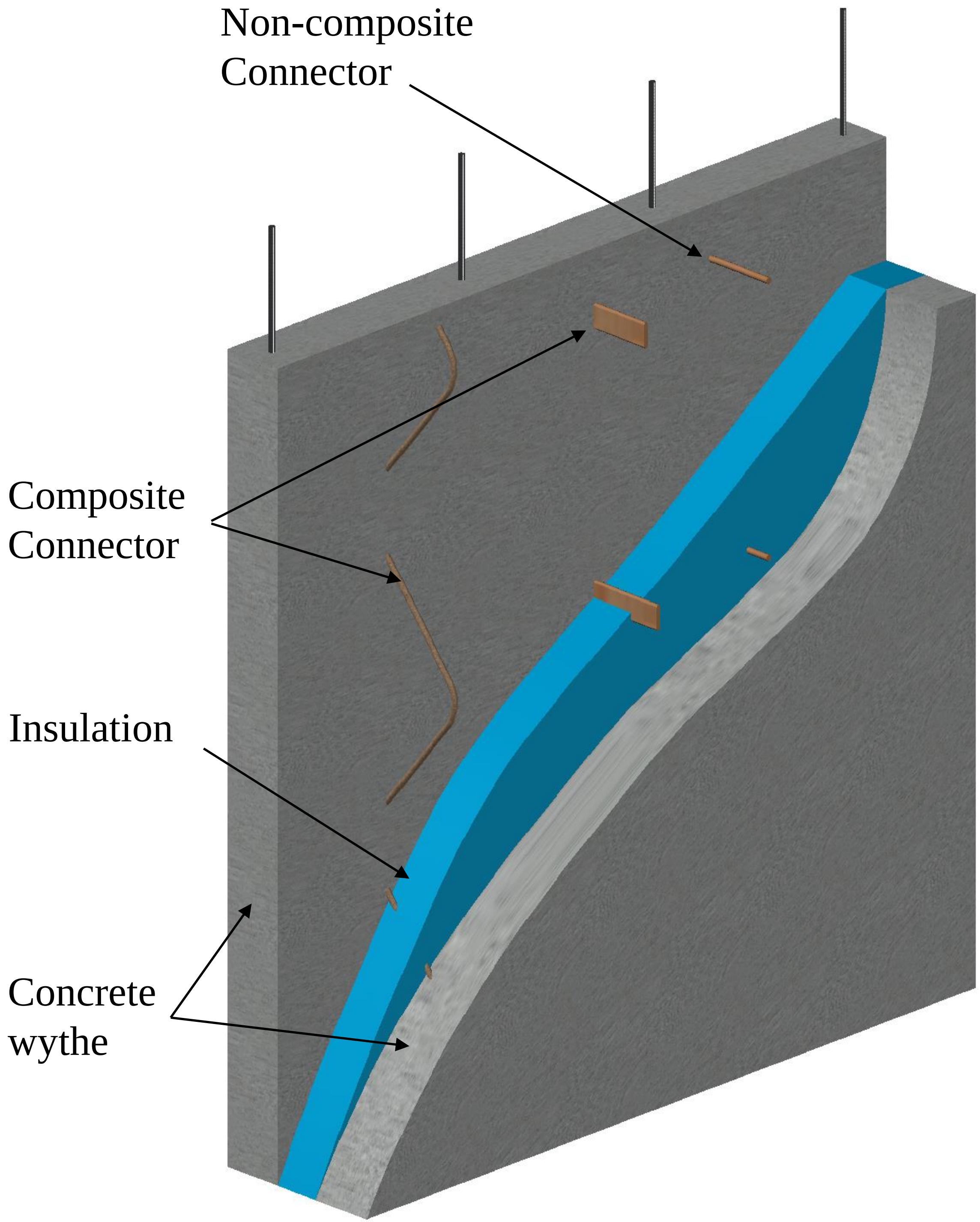
- Mitch Bloomquist
- Craig Coppersmith

OUTLINE

- Background
- Experimental Program and Results
- Proposed models
- Conclusion

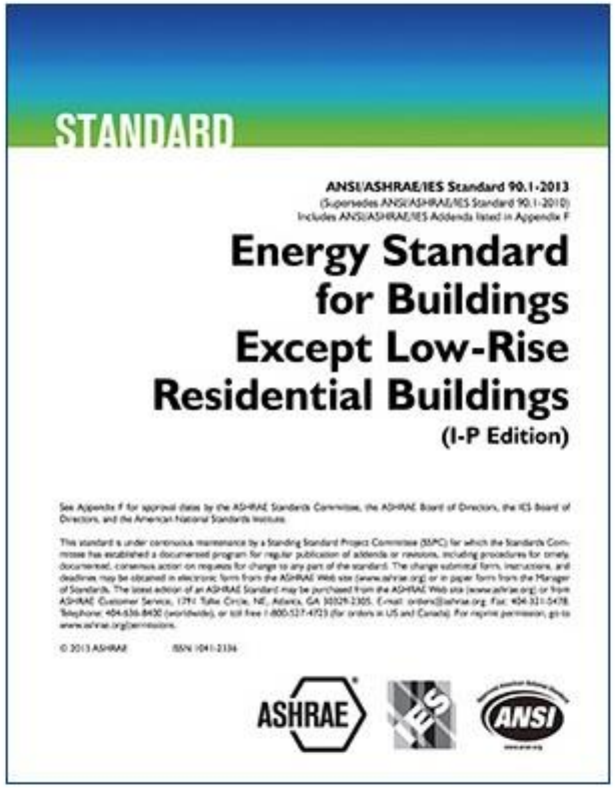
INTRODUCTION

- Typical consist of three layers
- Thermal efficiency
- Composite action
- Steel or fiber-reinforced plastic connection
- Cost and weight savings



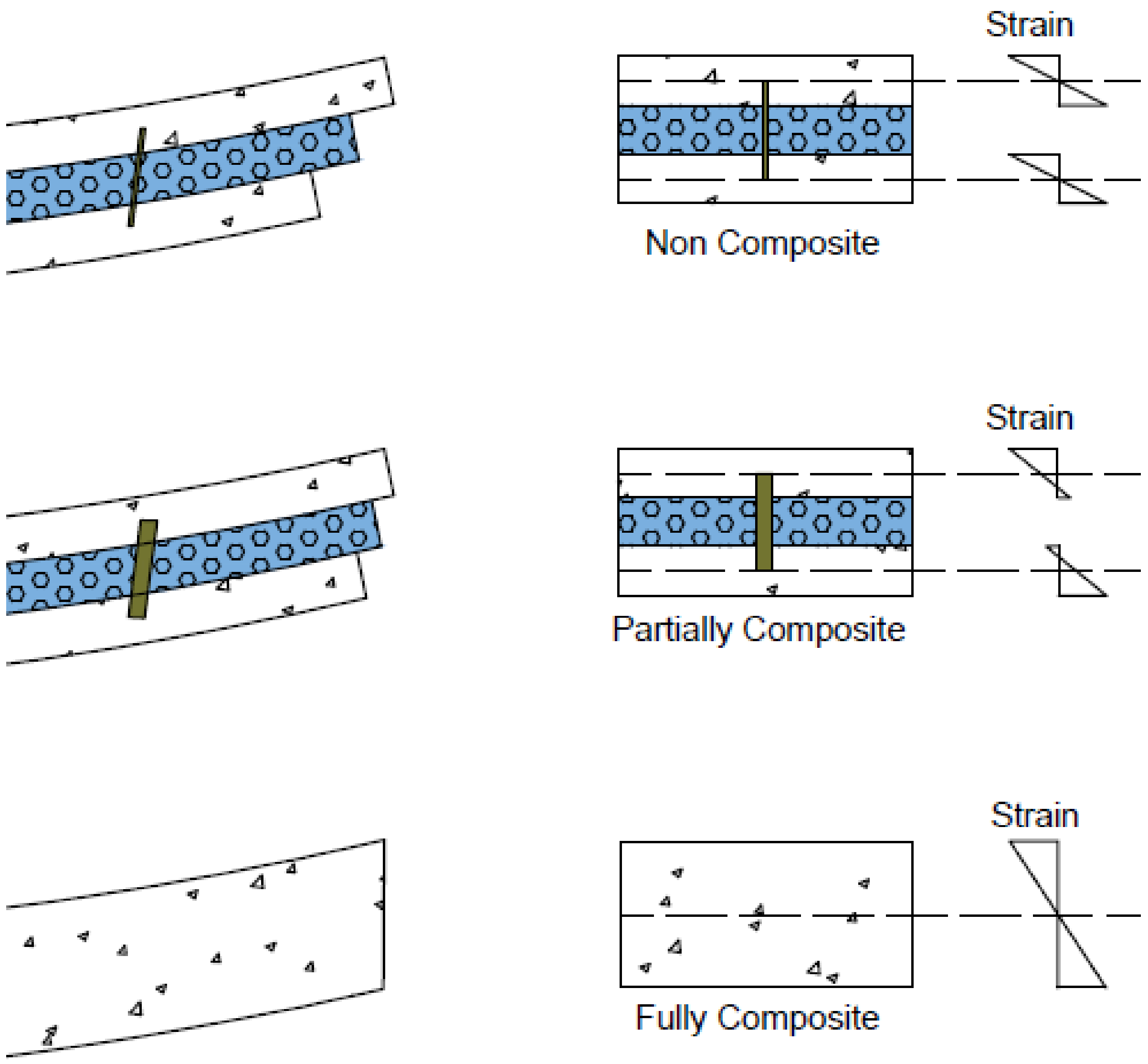
THERMAL EFFICIENCY

- Less Pollution
- Saves energy resources
- Cost effective
- Building Code Requirement



WHAT IS PARTIALLY COMPOSITE?

- Non-composite Panel
- Partially Composite Panel
- Fully Composite Panel.



WHY THIS WORK IS IMPORTANT?

- No public data exists for long sandwich panels with combined loads typical of tilt-up construction

- No code or official design recommendations exist for design tilt-up sandwich panels

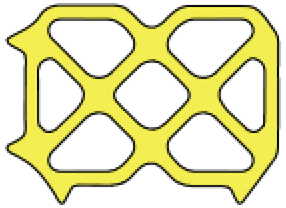
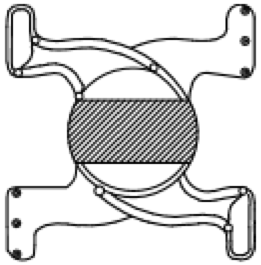
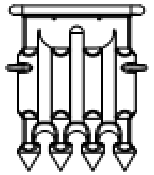
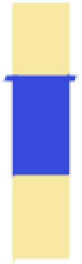
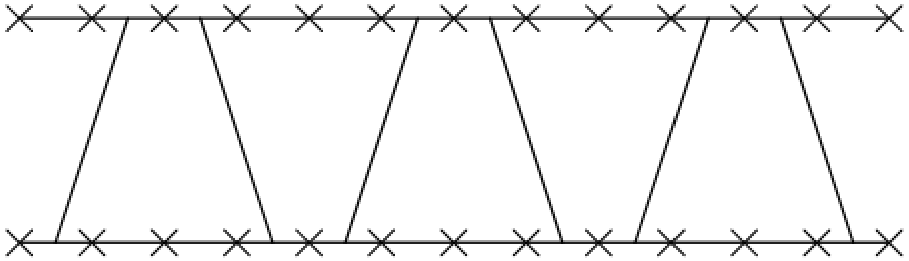
PROJECT GOALS

1. Obtain information on panels with a variety of insulated wall panel connectors.
2. Predict composite panel deformations to estimate second order bending
3. Predict composite panel connector failures and forces.

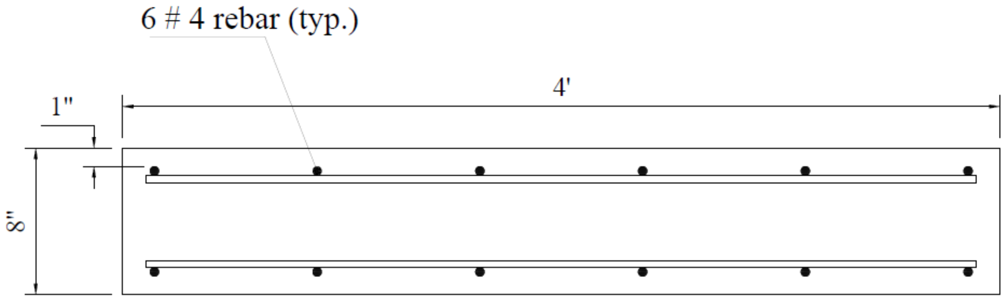
SIGNIFICANCE OF WORK

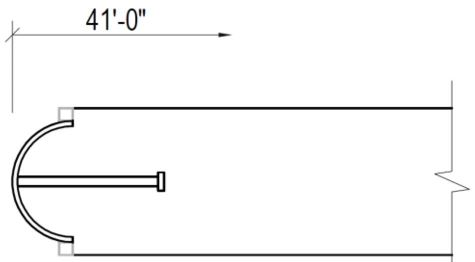
1. To provide engineers, contractors, and others information to enable the fabrication the tilt-up sandwich panels
2. Understanding of the nature of partial composite behavior
3. Relate connector behavior to full-scale behavior

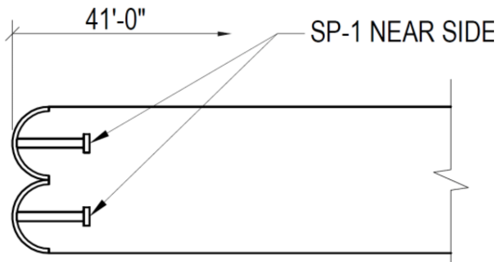
CONNECTORS

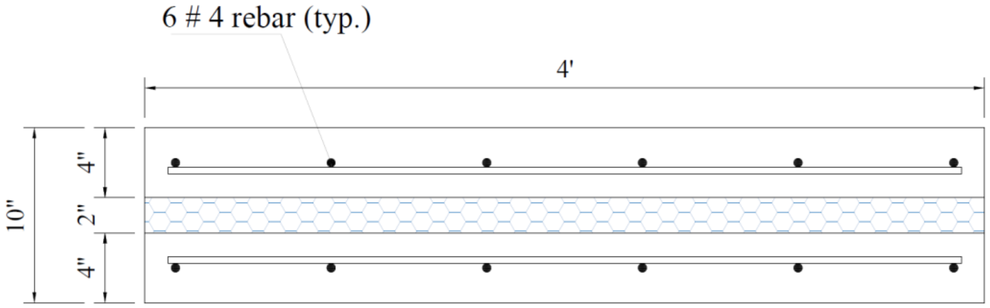






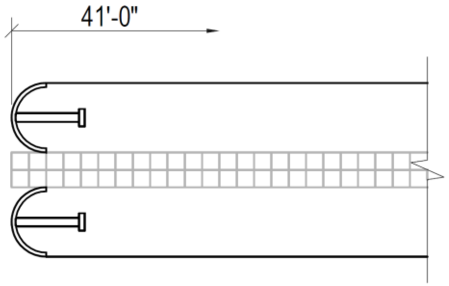
SOLID AND SANDWICH PANEL (CROSS SECTION)



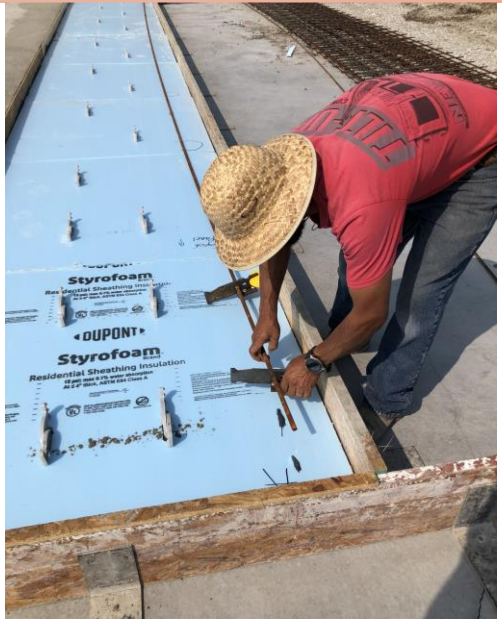






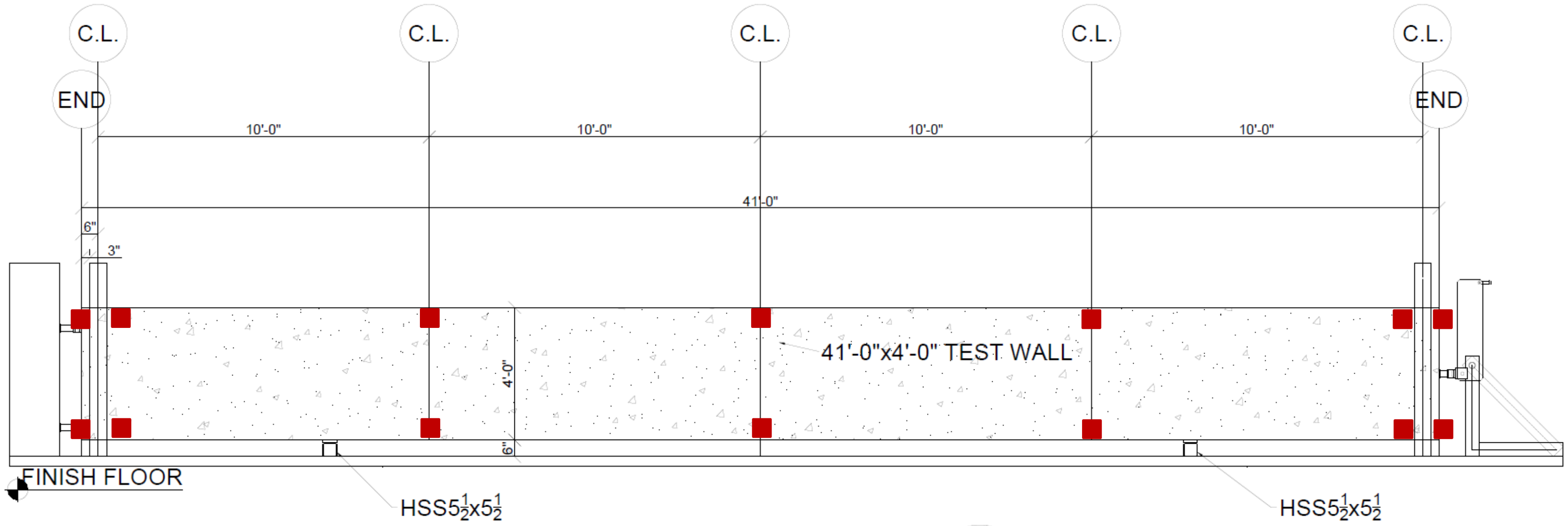


SPECIMENS CONSTRUCTION PROCESS



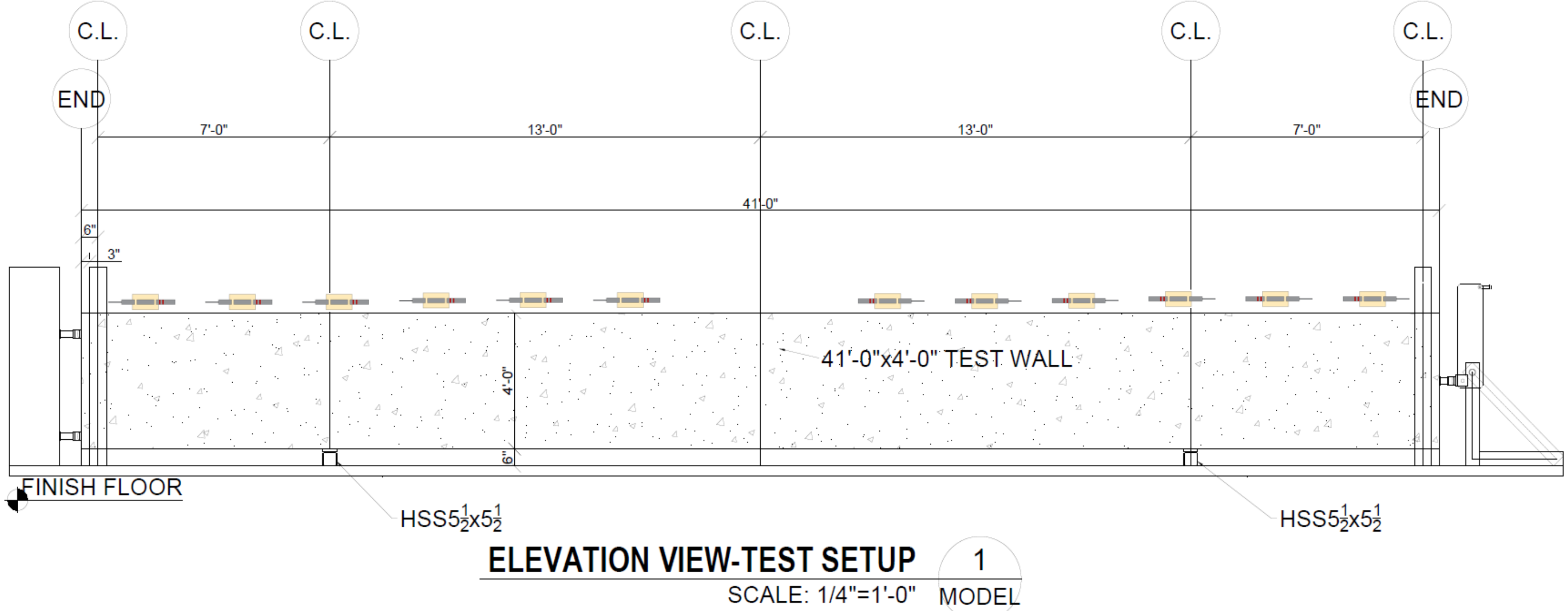
TEST SET UP

TEST SETUP FOR FLEXURAL TESTING



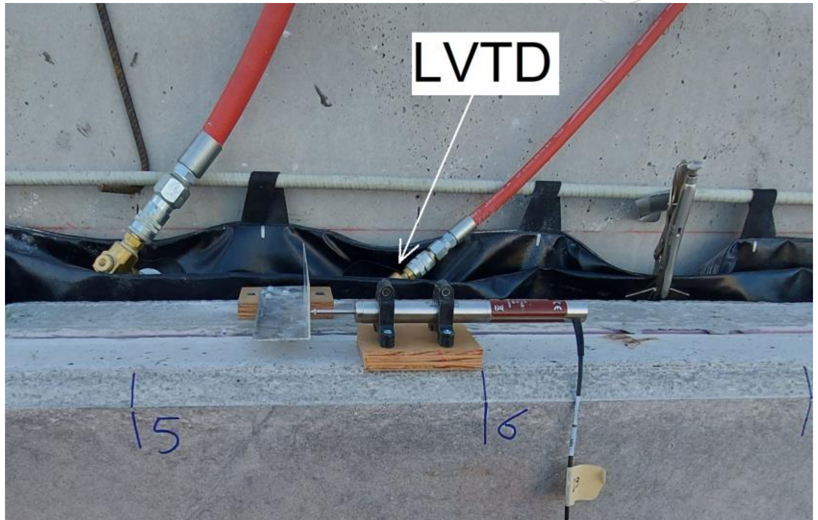
- **16 Deflection measurements**

TEST SETUP FOR FLEXURAL TESTING



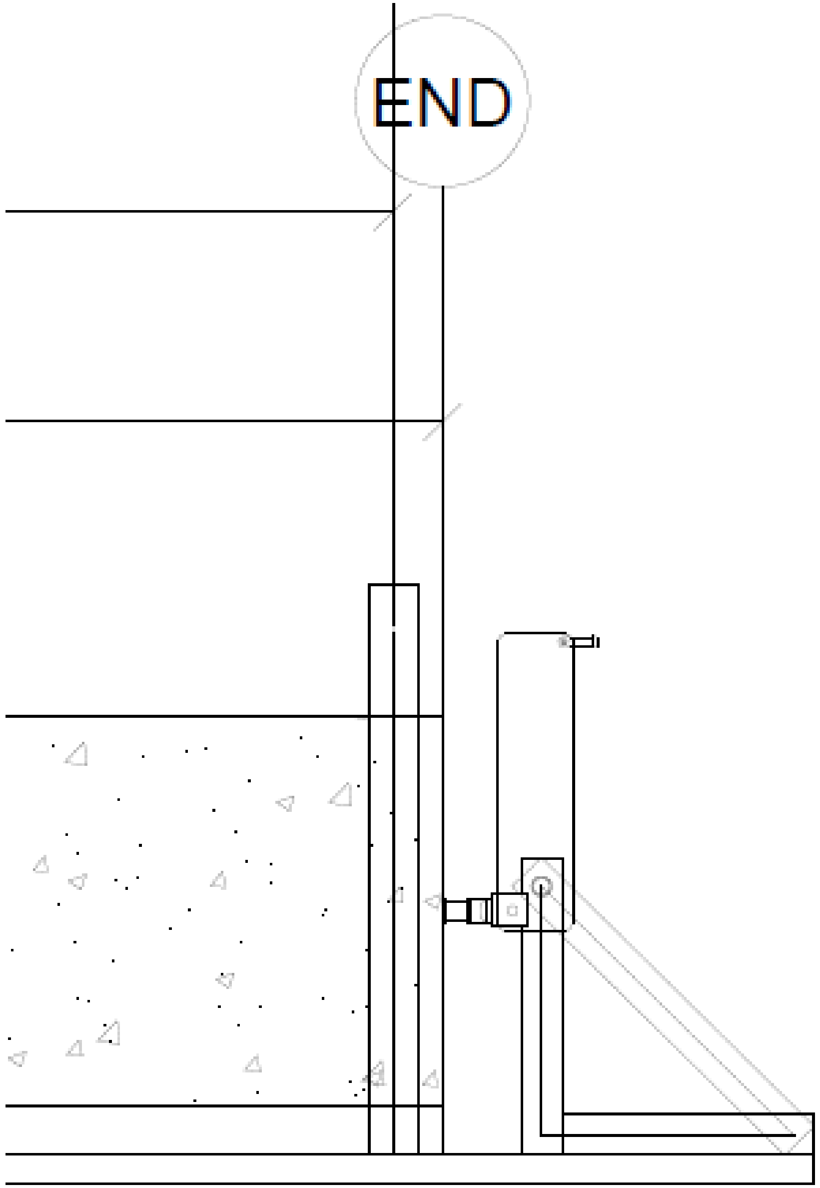
- **12 LVTDs**

-To measure the slip between the concrete wythe



TEST SETUP FOR FLEXURAL TESTING

- **Rocker Arms**



TEST SETUP FOR FLEXURAL TESTING

- **Rocker Arms**

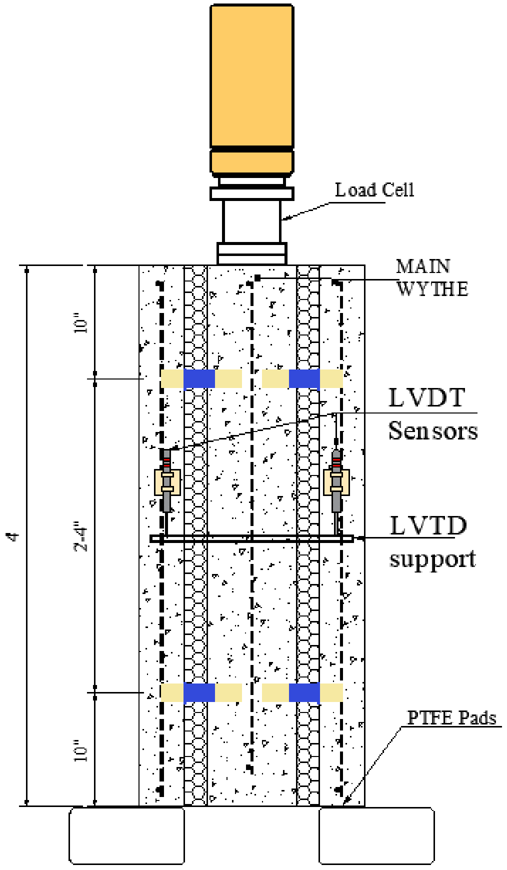
TEST SETUP FOR FLEXURAL TESTING

- **Rocker Arms**

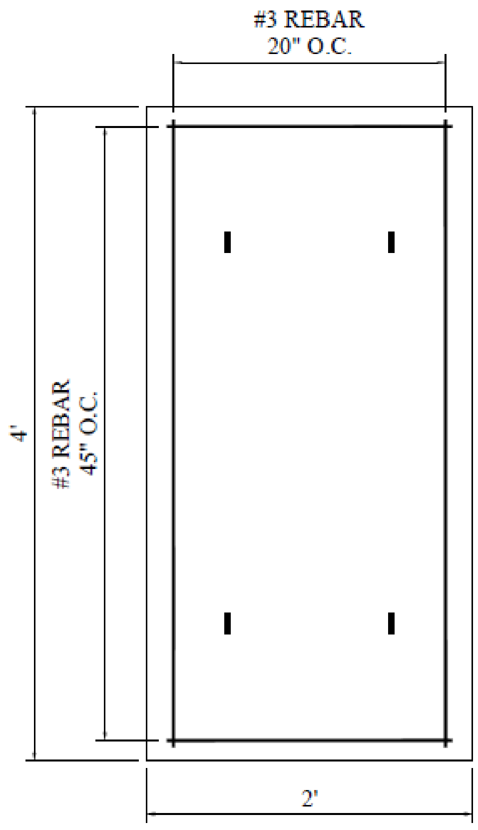
TEST SETUP FOR FLEXURAL TESTING

- **Airbag**

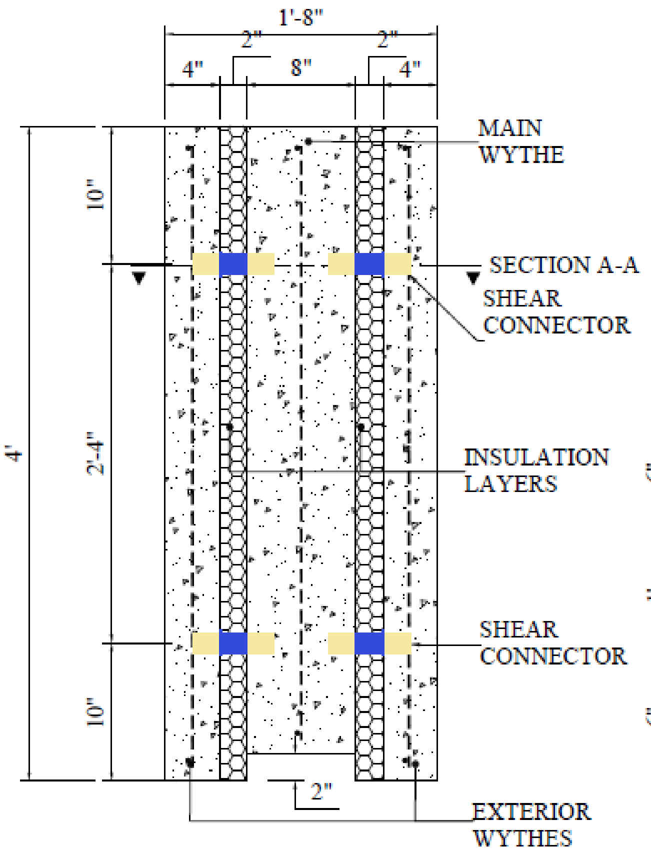
DOUBLE SHEAR



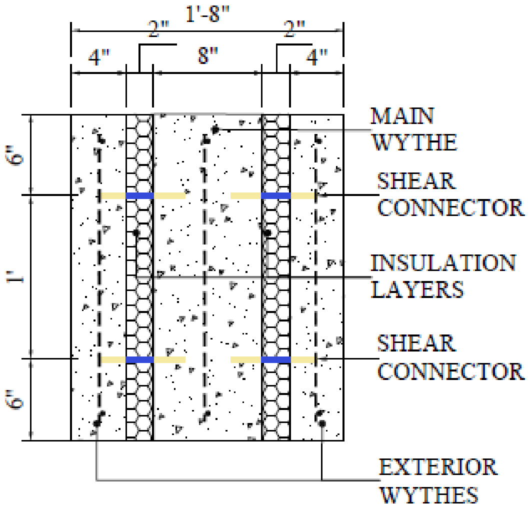
SHEAR TEST SPECIMEN



SPECIMEN REINFORCING

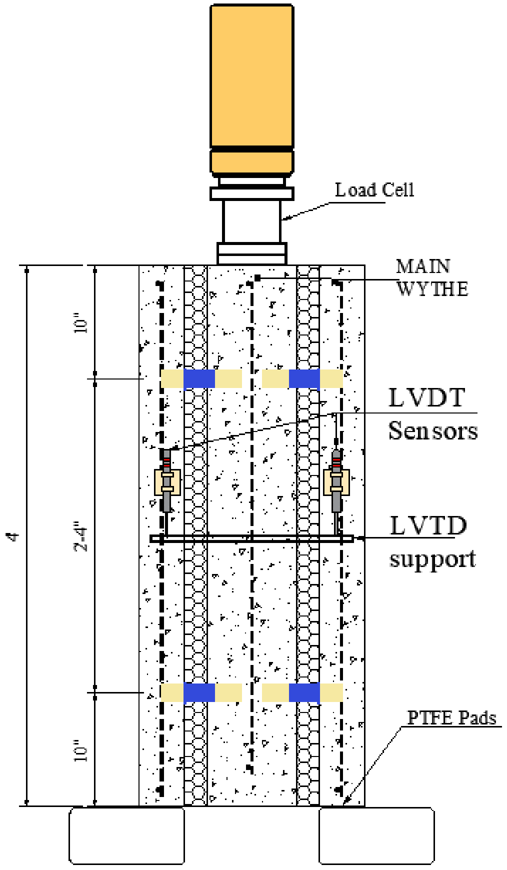


SHEAR TEST SPECIMEN



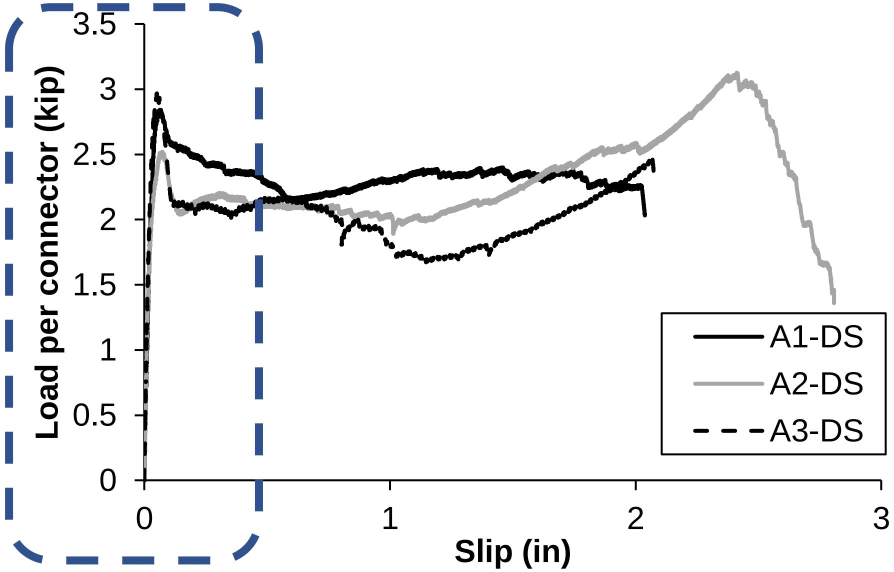
SECTION A-A

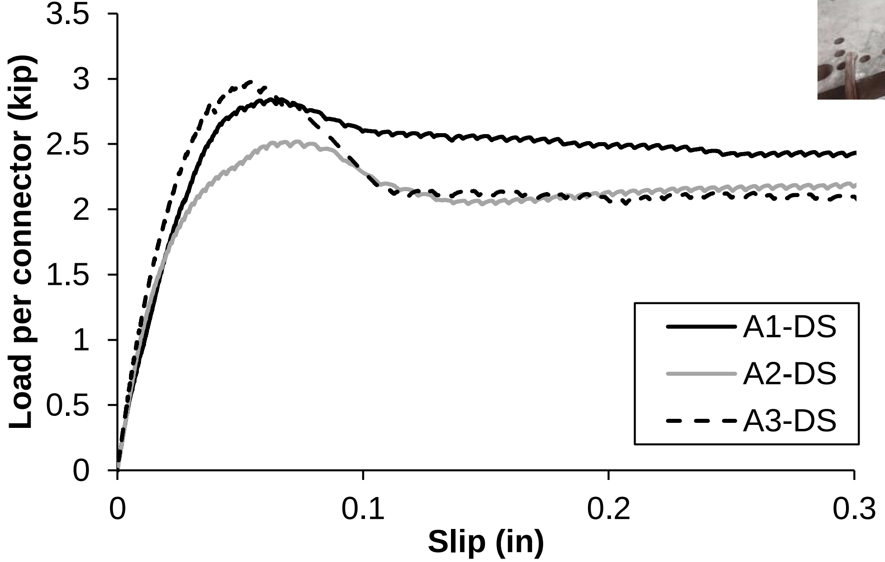
DOUBLE SHEAR



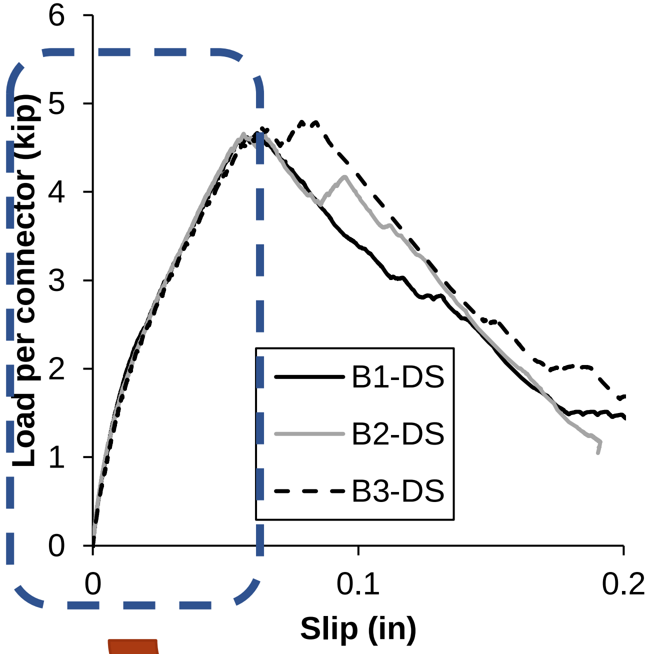
SHEAR TEST SPECIMEN

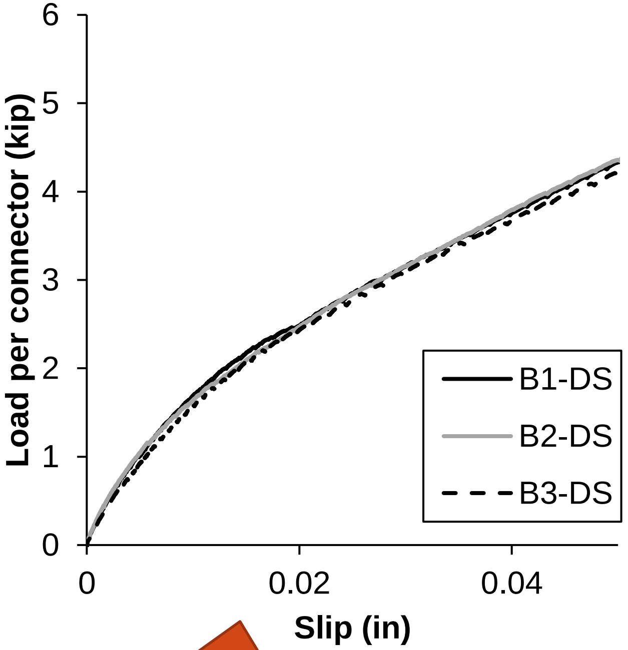
DOUBLE SHEAR TESTS FOR A



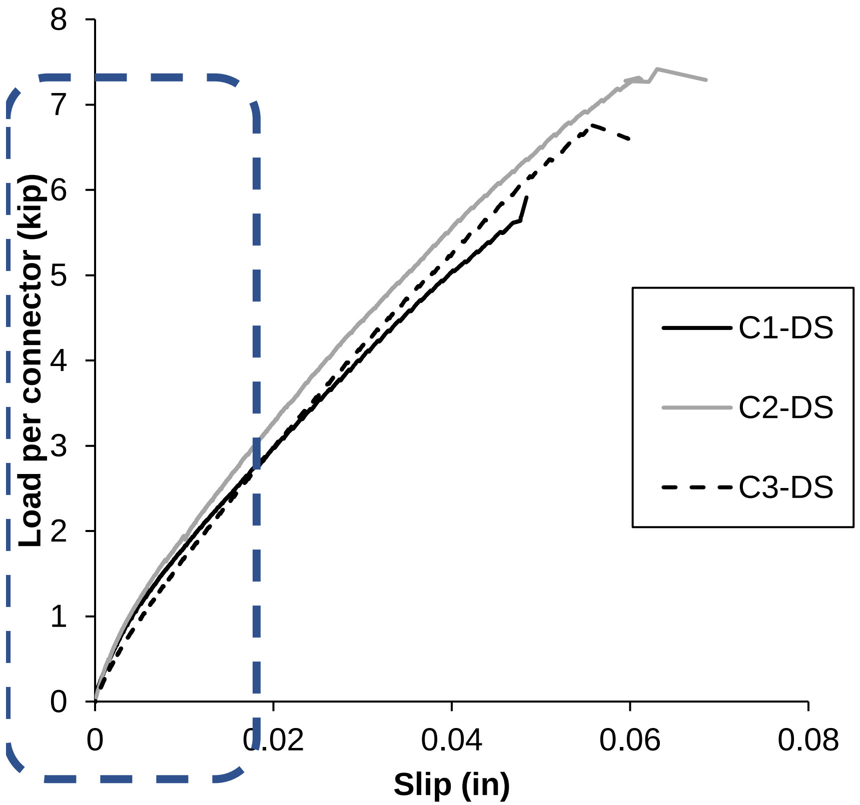


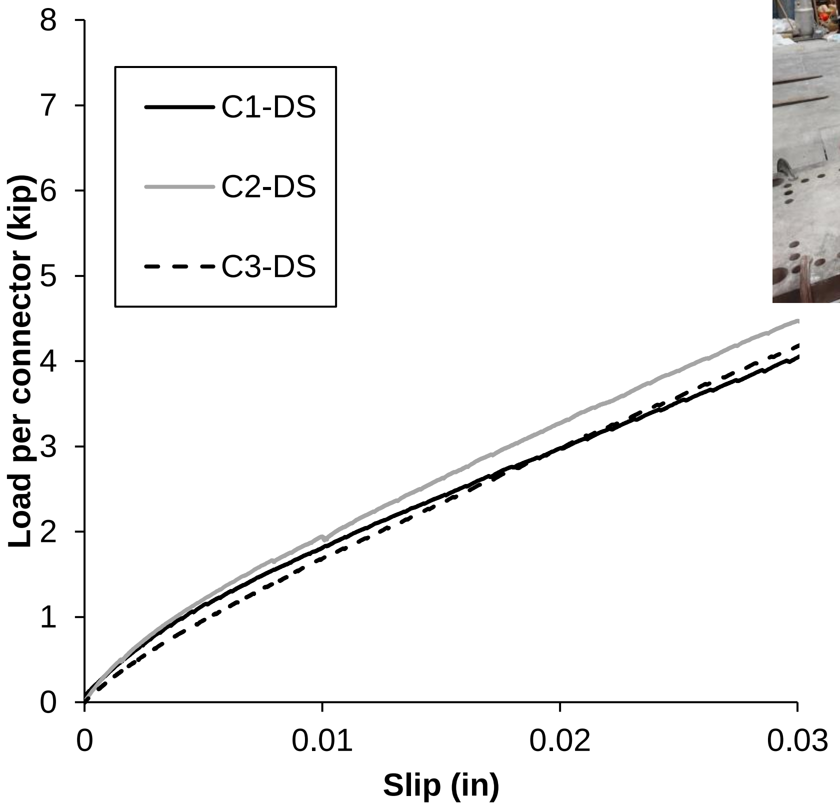
DOUBLE SHEAR TESTS FOR B



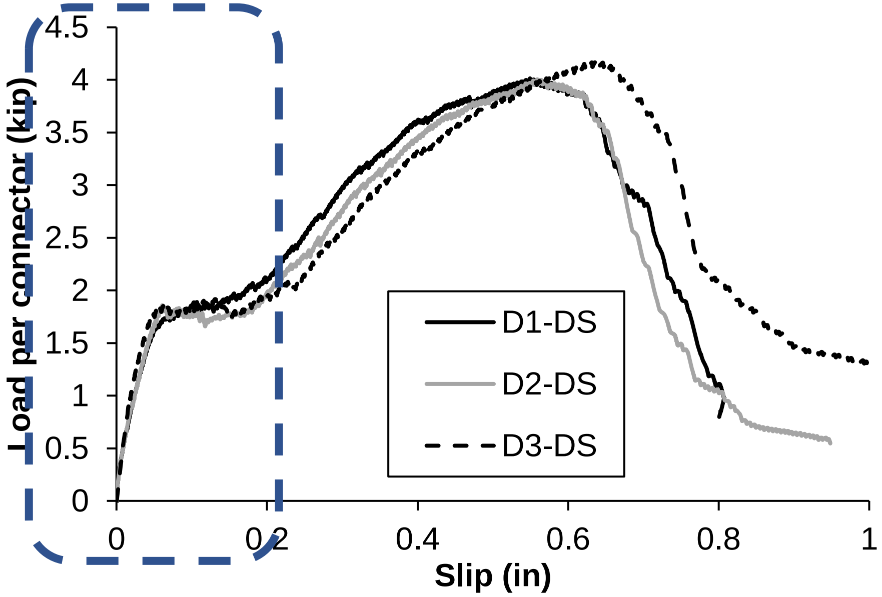


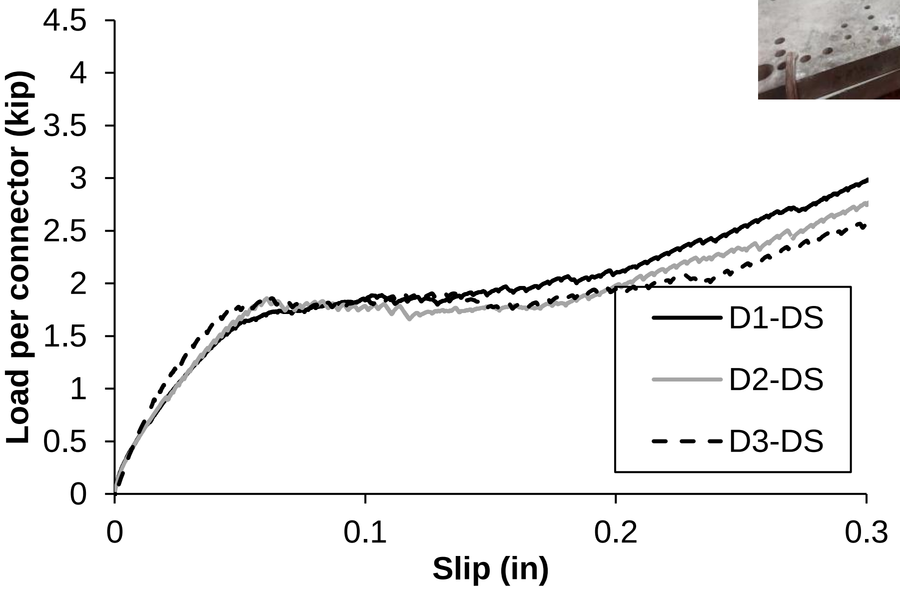
DOUBLE SHEAR TESTS FOR C



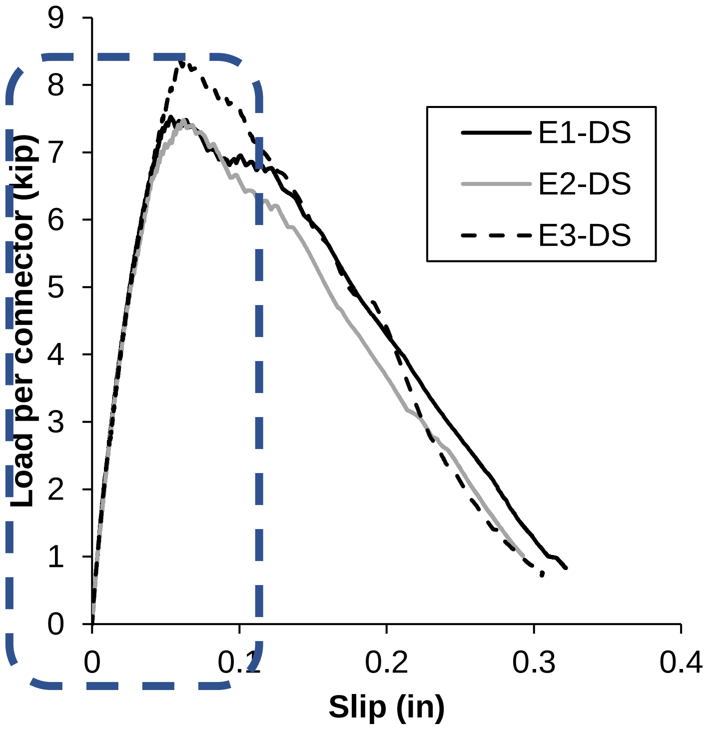


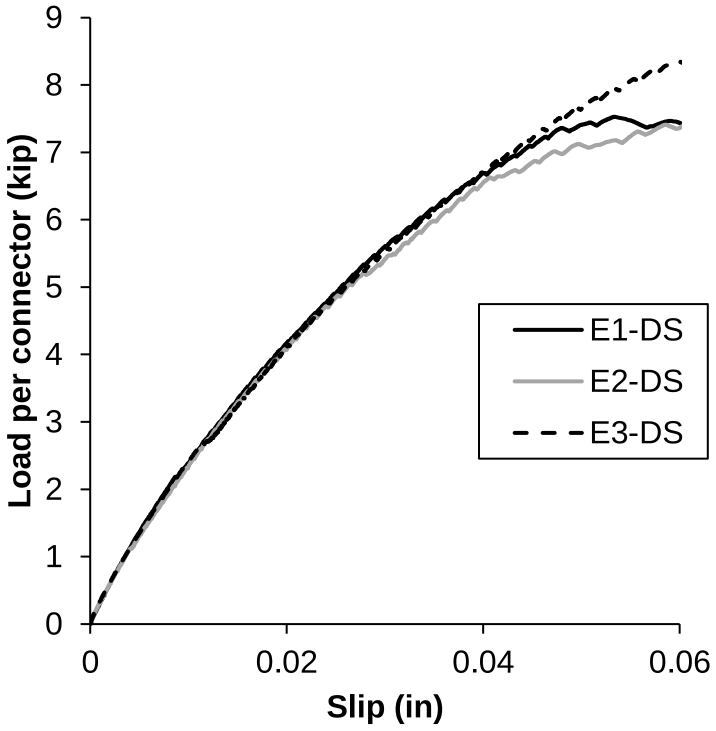
DOUBLE SHEAR TESTS FOR D





DOUBLE SHEAR TESTS FOR E





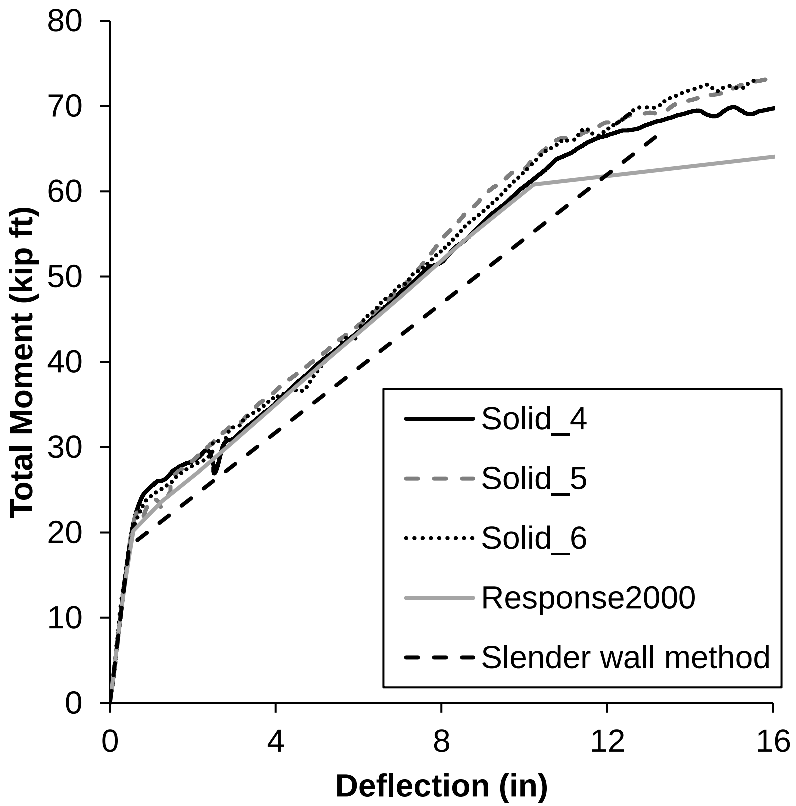
SOLID PANEL

Observations:
Average Ultimate Moment was 72 kip*ft

Average deflection at Ultimate Moment was 12 in

Average cracking Moment was 22 kip*ft

Failure type was steel yielding



SOLID PANEL

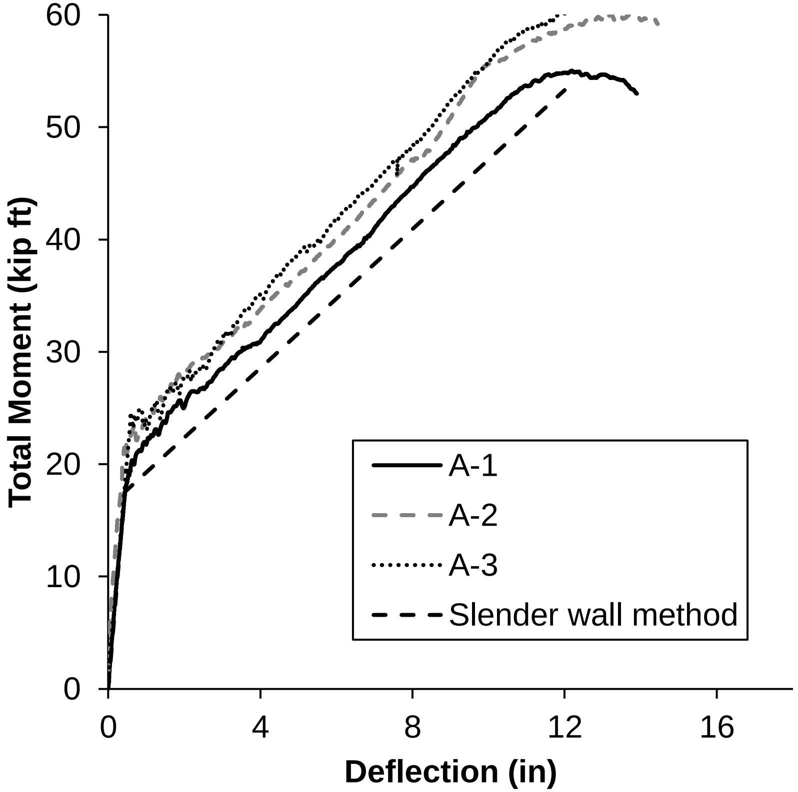
A PANELS

Observations:
Average Ultimate Moment is 58 kip*ft

Average deflection at Ultimate Moment was 12 in

Average cracking Moment was 21 kip*ft

Failure type was steel yielding



Equivalent Solid Panel	kip*ft
Design Moment	53
Cracking Moment	17.5

A PANELS

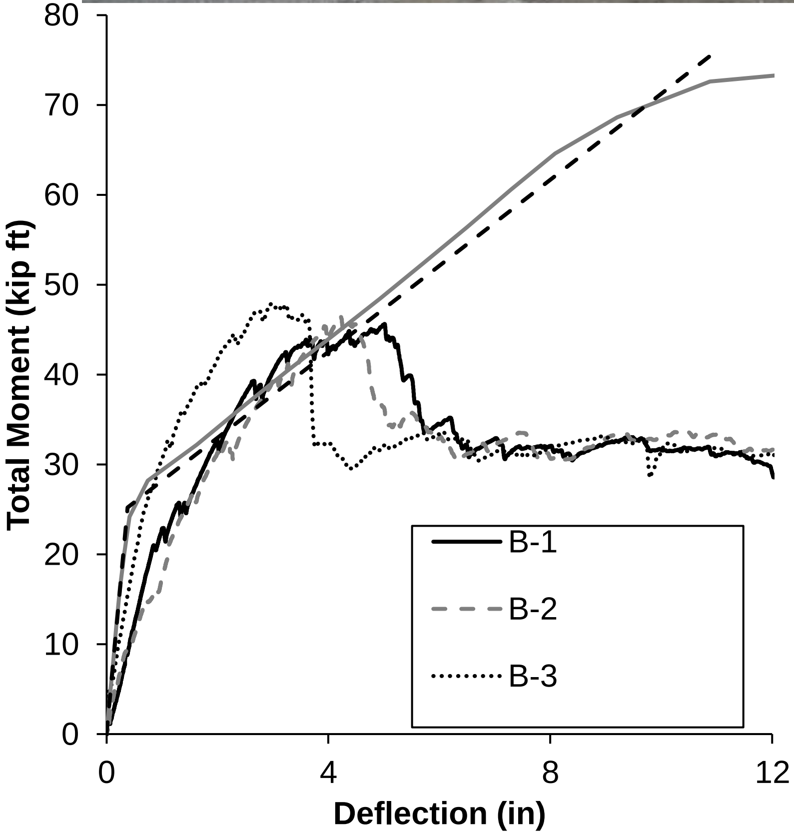
B PANEL

Observations:
Average Ultimate Moment was 45 kip*ft

Average deflection at Ultimate Moment was 4 in

Average cracking Moment was 18 kip*ft

Failure type was horizontal shear failure for B1-3



Equivalent Solid Panel	kip*ft
Ultimate Moment	78
Cracking Moment	25.2

C PANEL

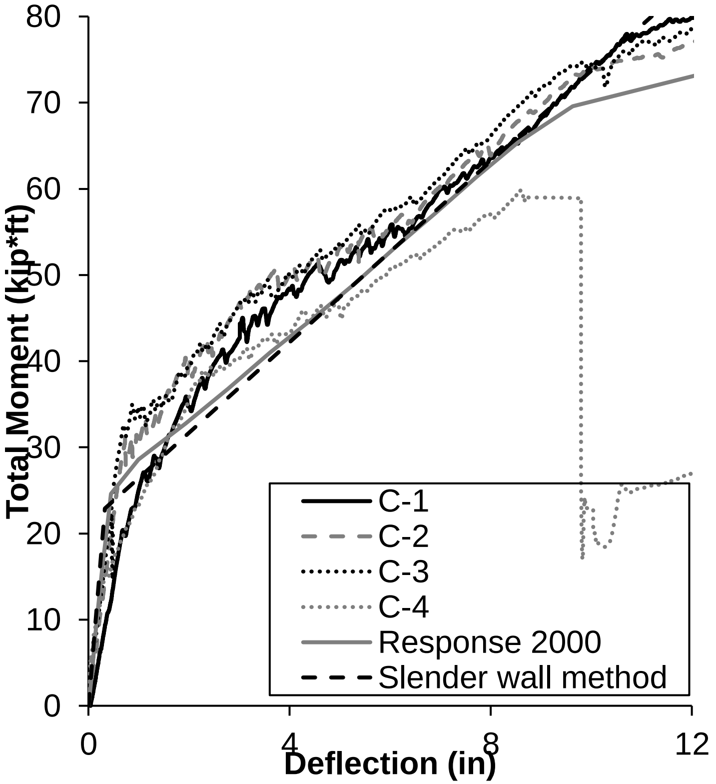
Observations:
Average Ultimate Moment was 75 kip*ft

Average deflection at Ultimate Moment was 11 in

Average cracking Moment was 23 kip*ft

Failure type was steel yielding C1-3

Failure type was horizontal shear failure for C4



Equivalent Solid Panel	kip*ft
Ultimate Moment	78
Cracking Moment	25.2

D PANEL

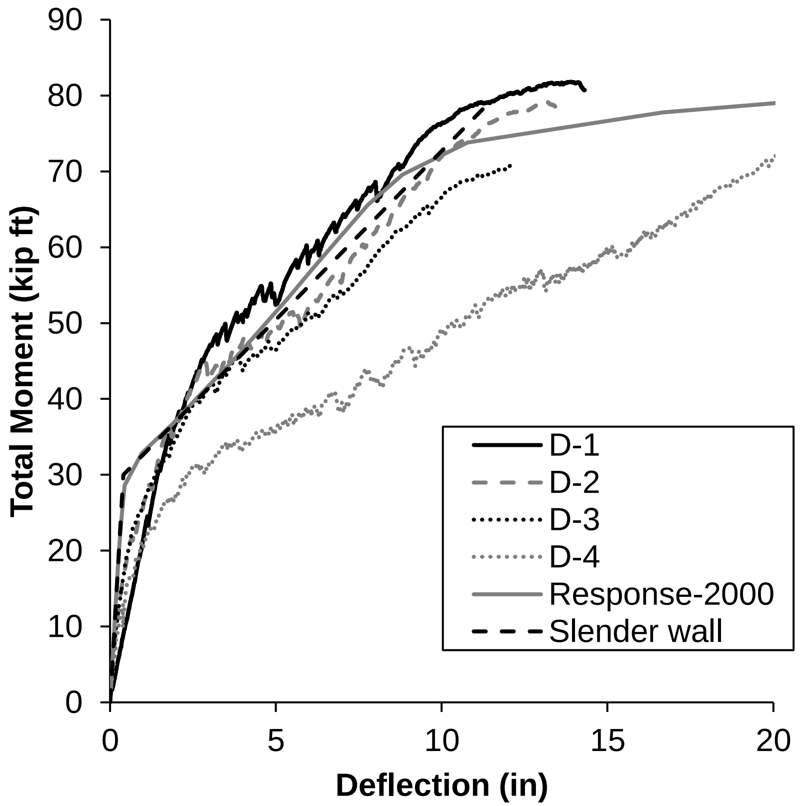
Observations:
Average Ultimate Moment was 75 kip*ft

Average deflection at Ultimate Moment was 11 in

Average cracking Moment was 23 kip*ft

Failure type was steel yielding D1-3

Failure type was horizontal shear failure for D4



Equivalent Solid Panel	kip*ft
Ultimate Moment	78
Cracking Moment	25.2

D PANEL

E PANEL

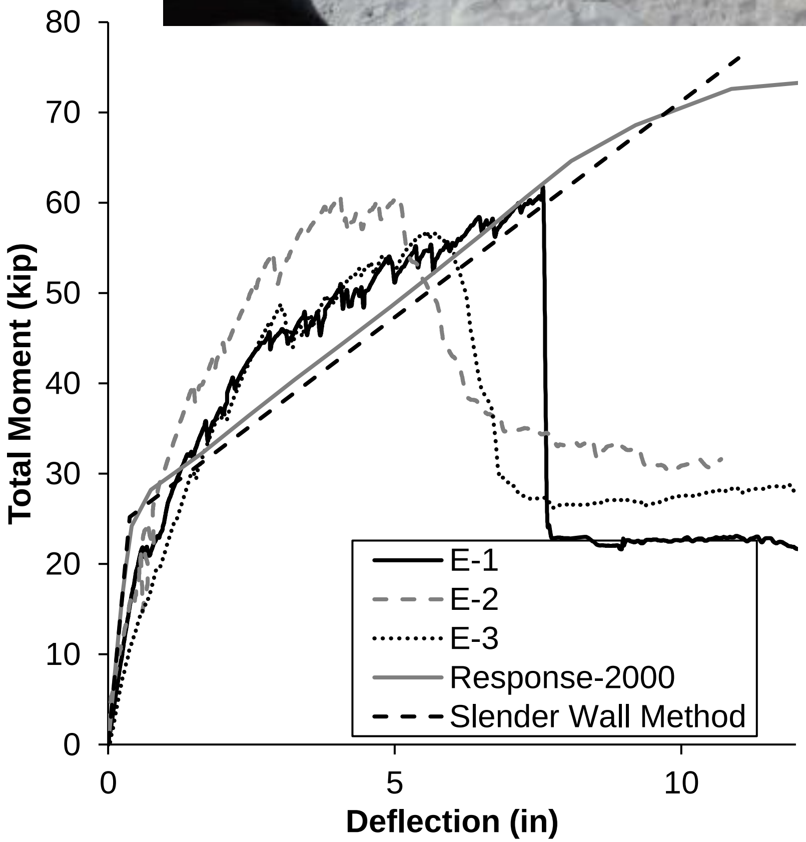
Observations:

Average Ultimate Moment was 58 kip*ft

Average deflection at Ultimate Moment was 6 in

Average cracking Moment was 20 kip*ft

Failure type was horizontal shear failure for E1-3



Equivalent Solid Panel	kip*ft
Ultimate Moment	78
Cracking Moment	25.2

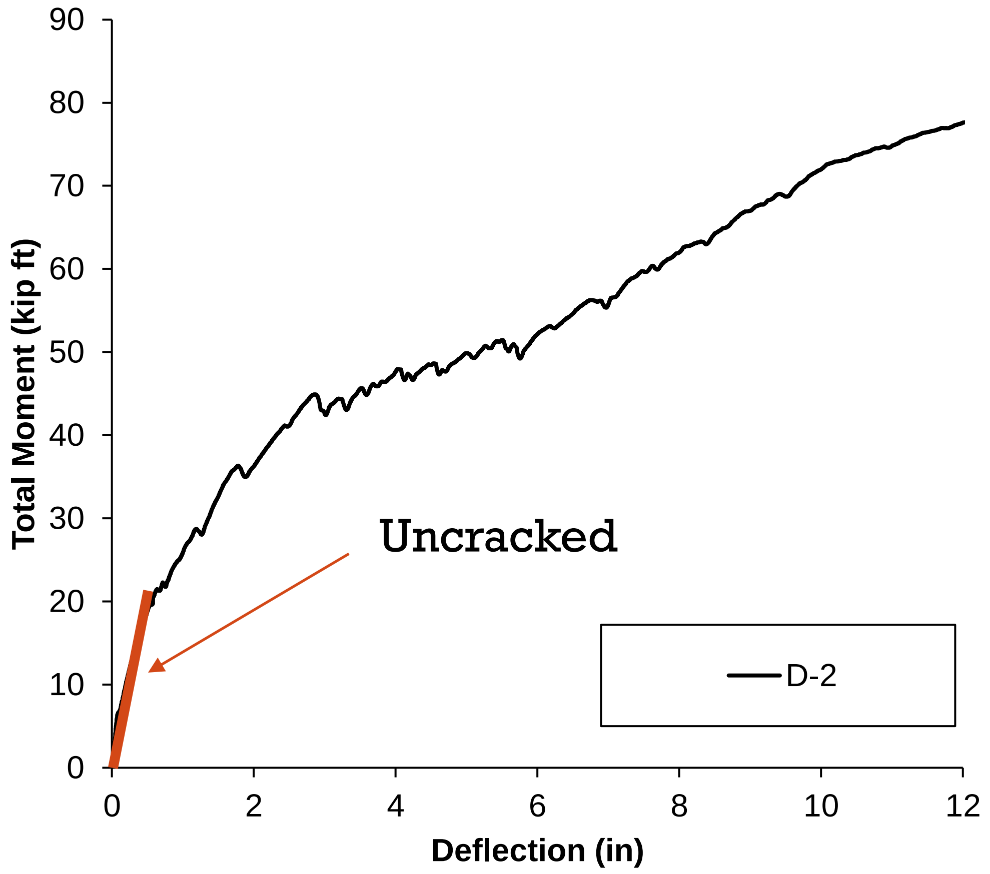
E PANEL

What can we learn from the experiments?

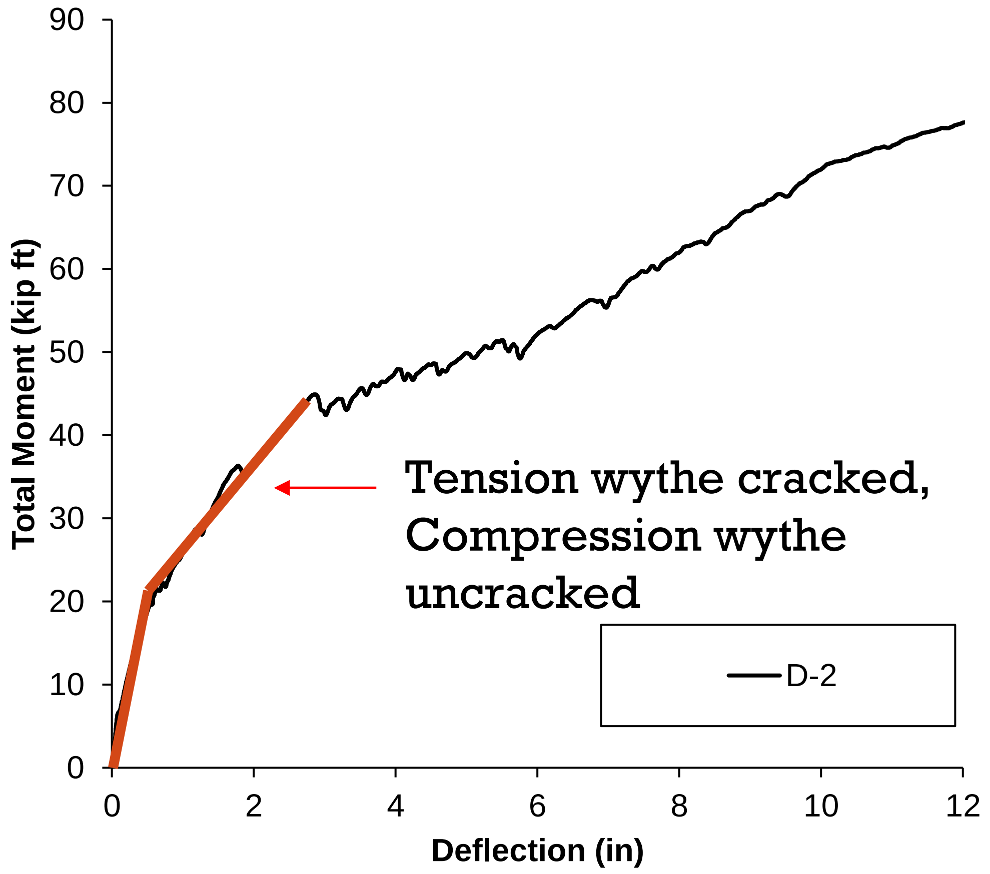
Engineers need a way to predict:

- Deformation of the panel under load
- Forces in concrete and steel
- Forces in the connectors

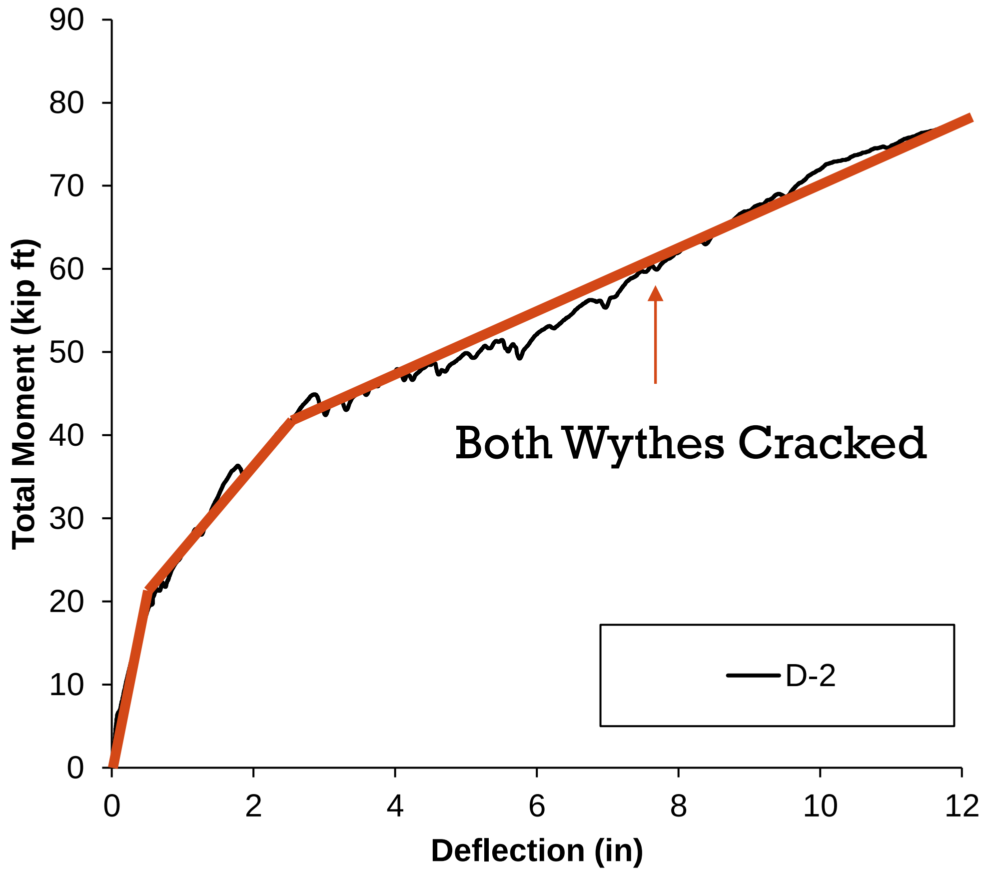
Can we predict panel deformation?



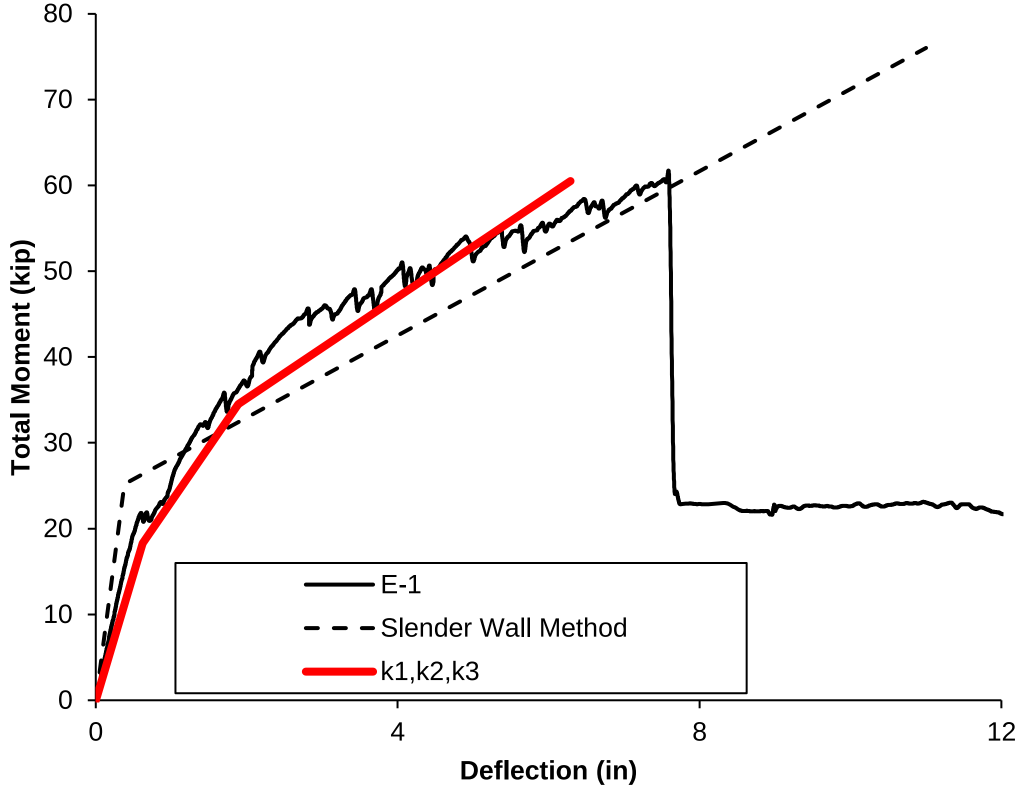
Can we predict panel deformation?

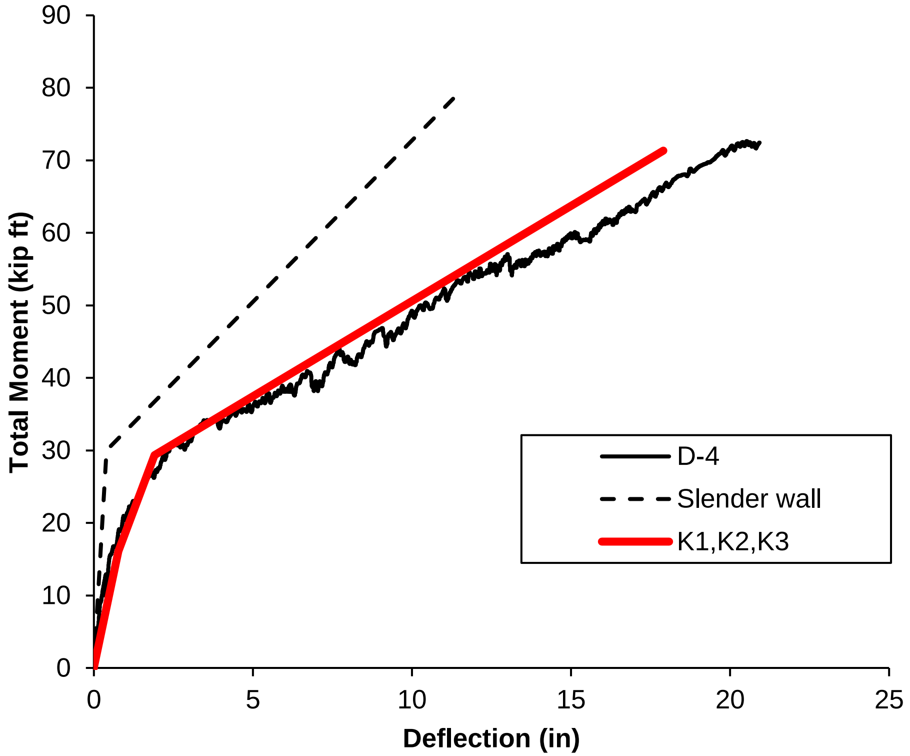


Can we predict panel deformation?



K1,K2,K3 Models





By assigning different wythe gross or cracked properties, the curve can be reproduced using elastic methods

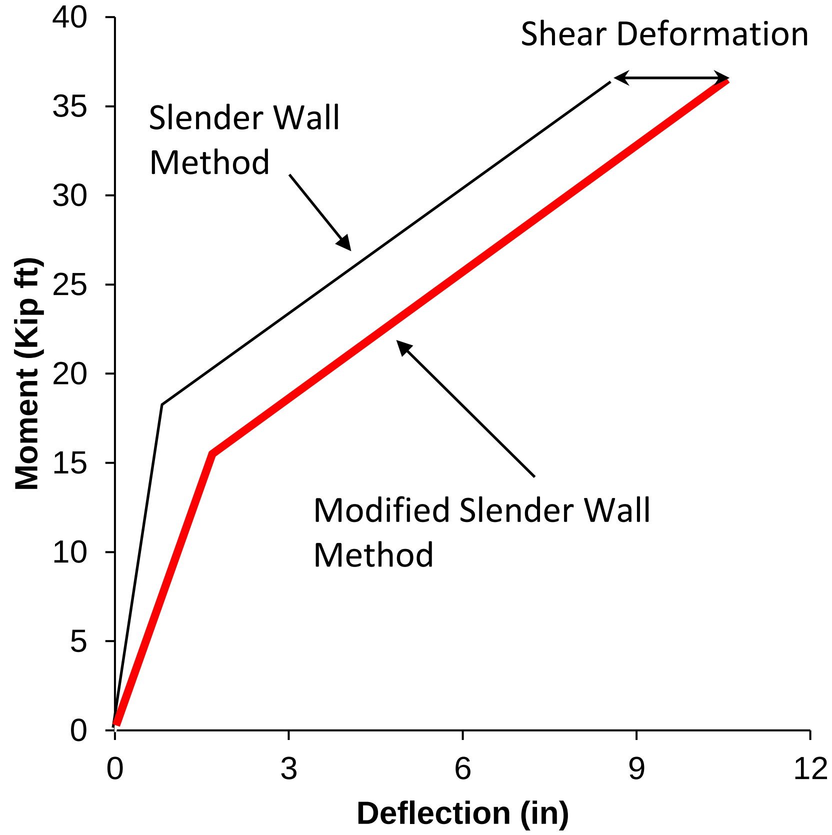
- MUST select proper cracking and tension stiffening models

Modified Slender wall Method for SWP

Modified slender wall method

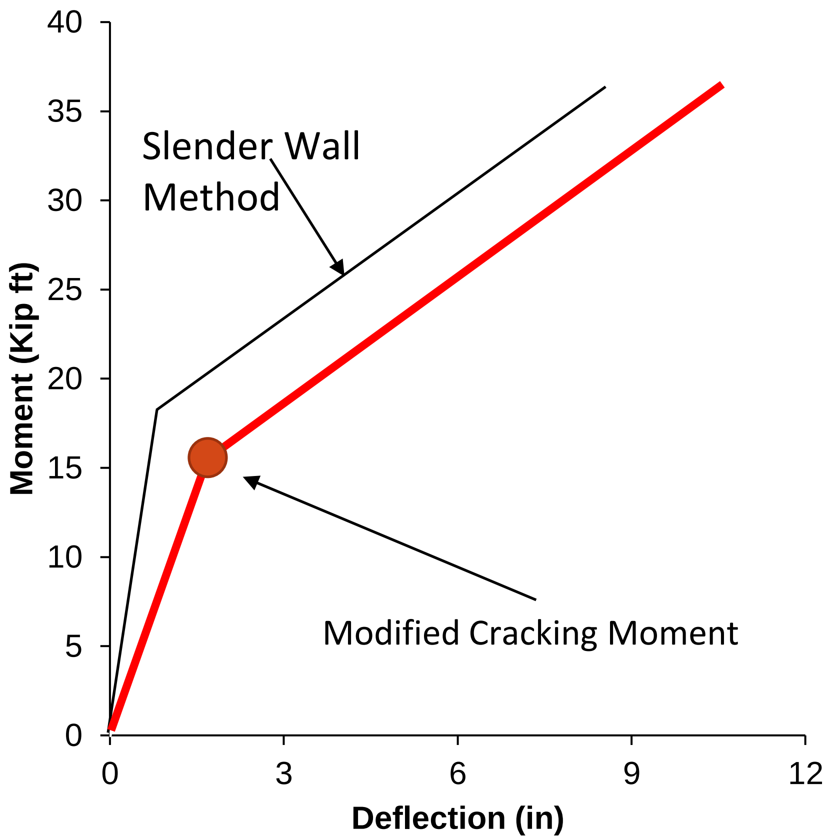
- Lower cracking moment
- Larger ultimate deformation, accounting for shear deformation

- Accounts for different connector properties using double shear data



Modified Slender wall Method for SWP

- Cracking moment can be calculated using existing methods
  - Connector suppliers currently provide this information
  - Several open-source methods available
    - Simplified Sandwich Beam Theory
    - Sandwich Beam Theory
    - Vierendeel Truss
    - Beam-Spring Model



Modified Slender wall Method for SWP

- Shear deformation: deflection due to the slip of the connectors

$$\text{Shear deformation} = (\Delta_{cr,PC} - \Delta_{cr,FC})\frac{\delta_{ul}}{\delta_{cr}}$$

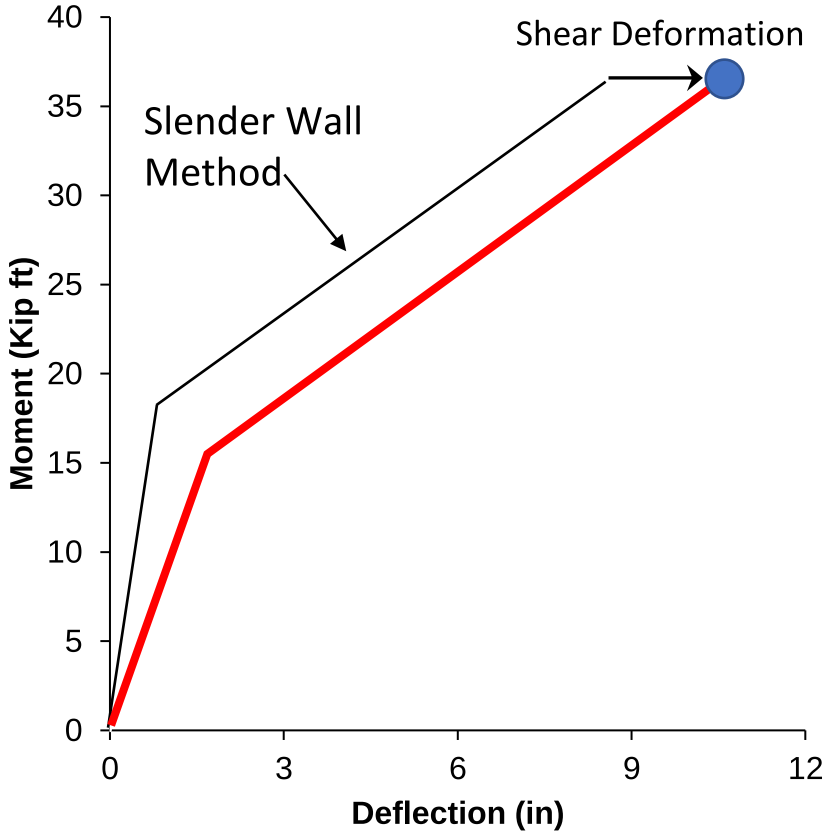
Where:

$\Delta_{cr,PC}$= deflection at cracking moment of PC panel

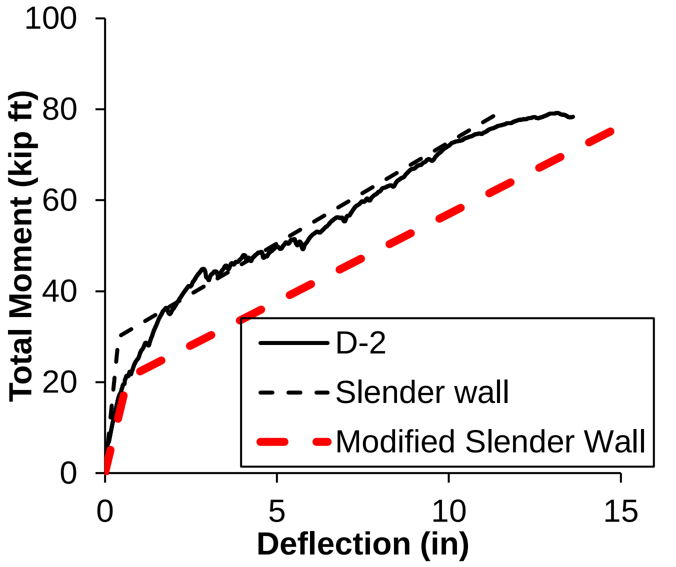
$\Delta_{cr,FC}$= deflection at cracking moment of solid panel

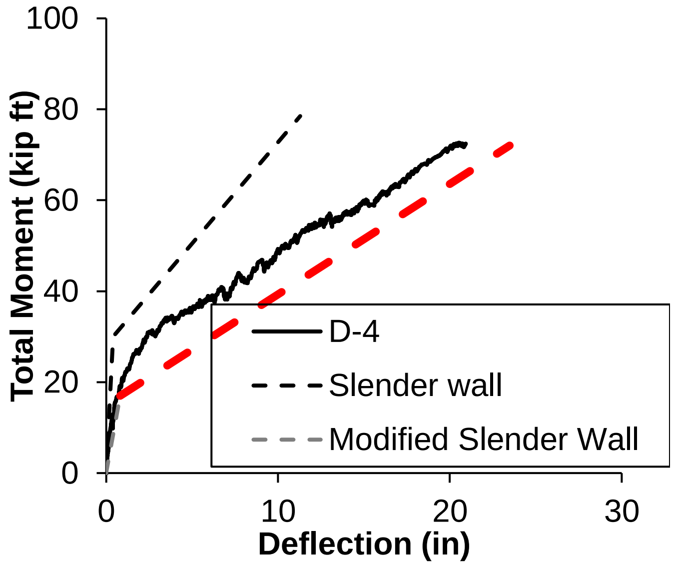
$$\delta_{ul} = \min\begin{cases}\text{Max Slip from the double shear test}\\ \text{Max Slip of the linear slip profile that give Fsum equal to } (A_s * f_y)\end{cases}$$

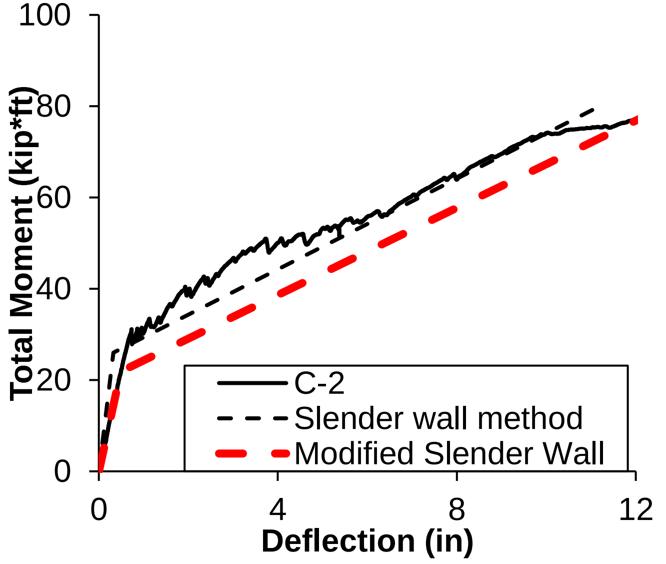
δ_{cr} = Slip of the end connector at cracking moment of PC panel

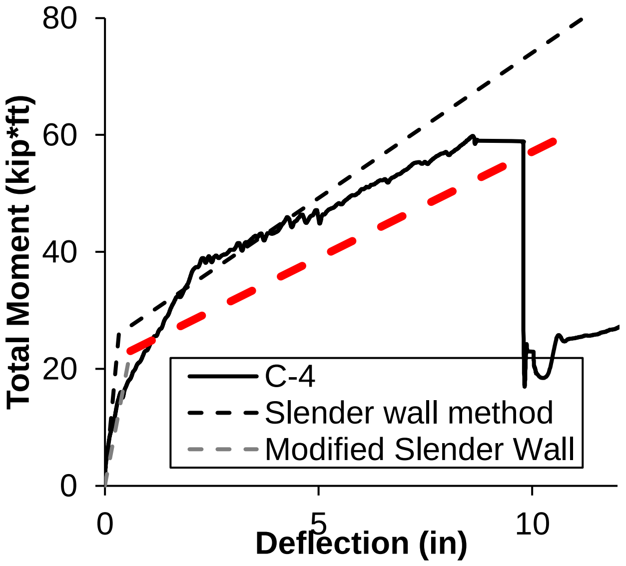


Modified Slender wall Method for SWP

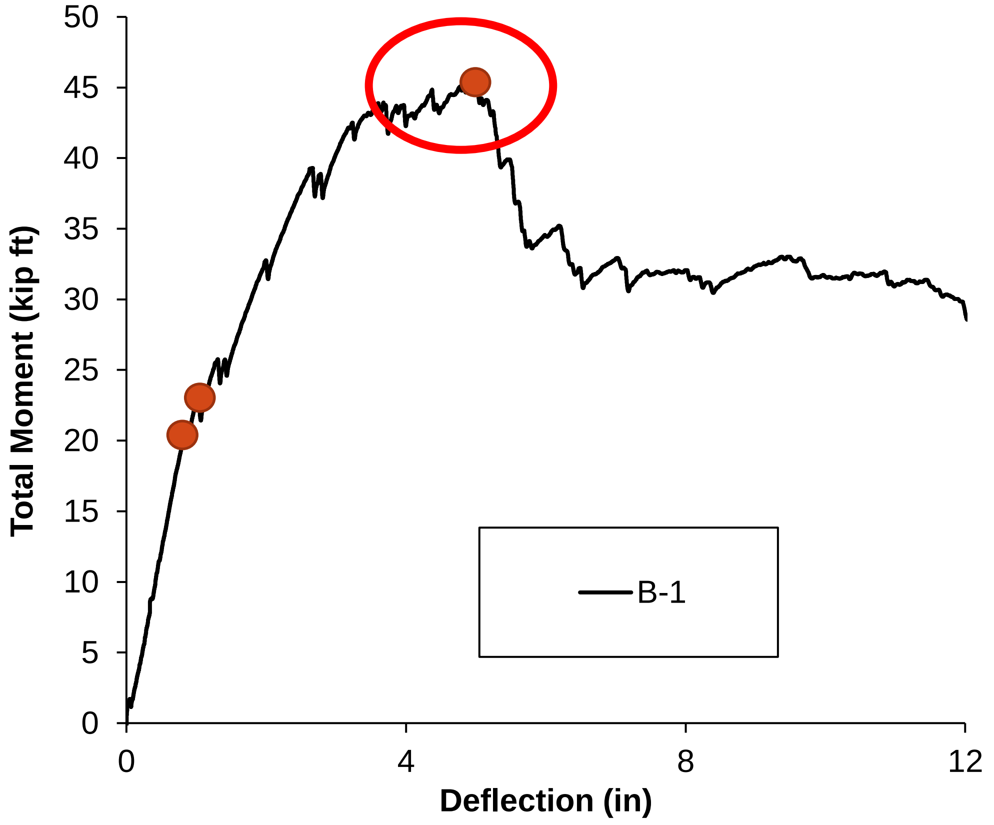


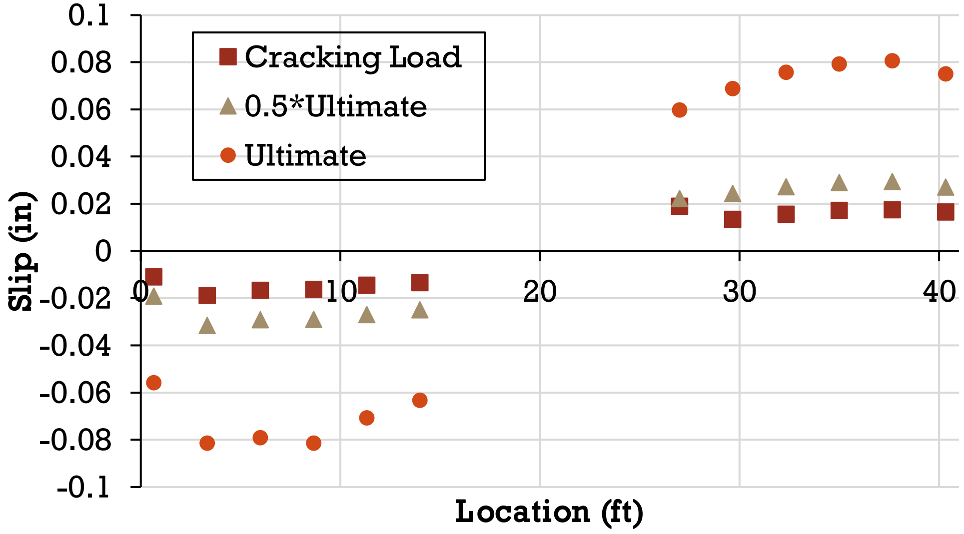






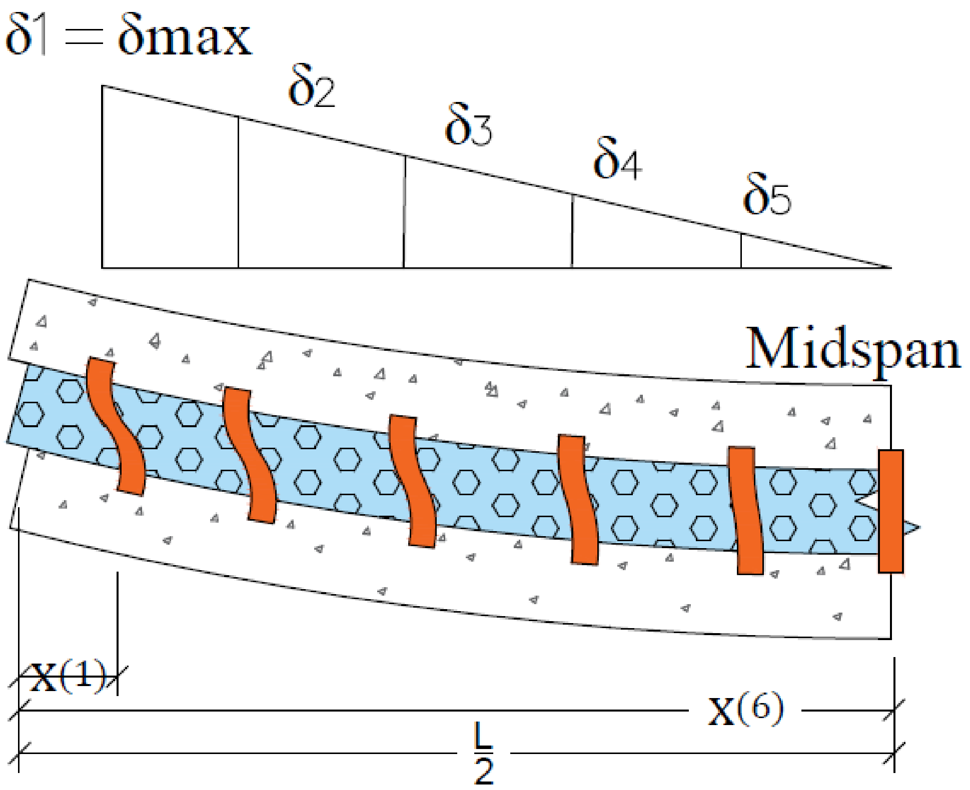
Can we predict shear failure?

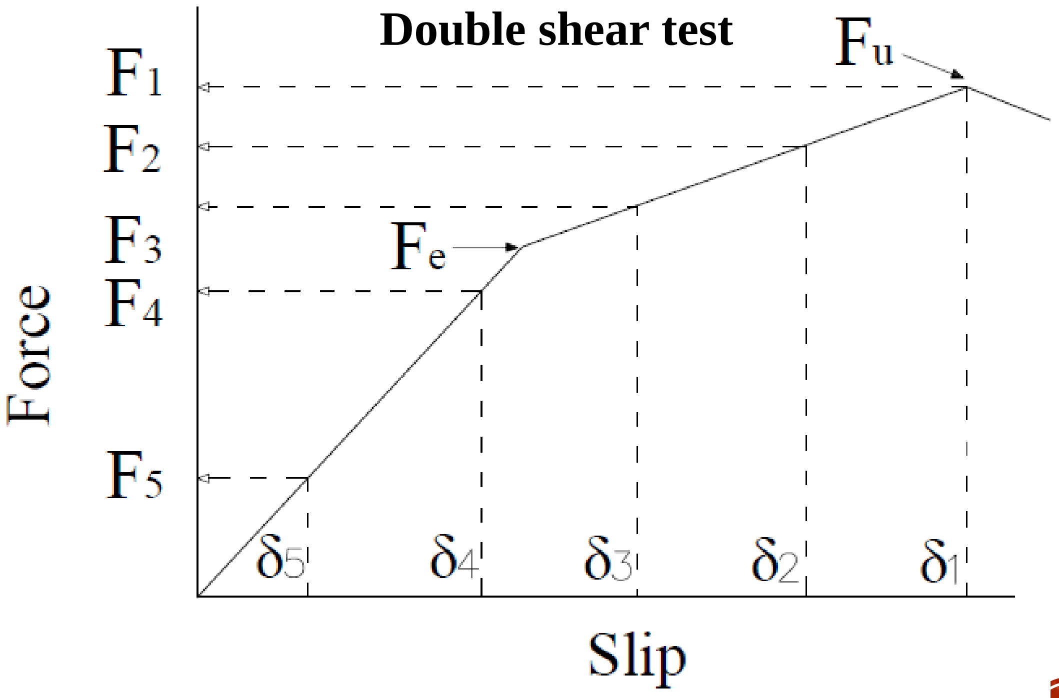




Shear Slip Method

As the wythes rotate relative to one another, the connectors prevent this movement.





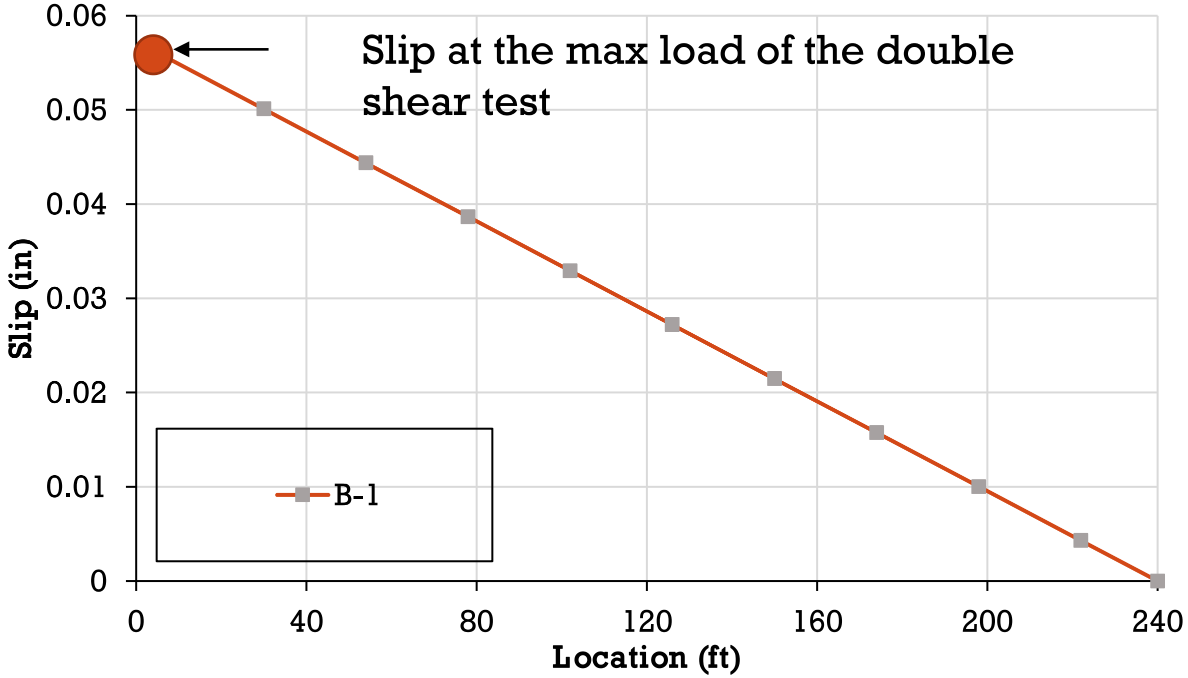
Shear Slip Method

Linear Slip profile

This assumption is conservative

$$\delta(i) = \delta_{max} * \frac{\frac{l_c}{2} - x_i}{\frac{l_c}{2} - x_1}$$

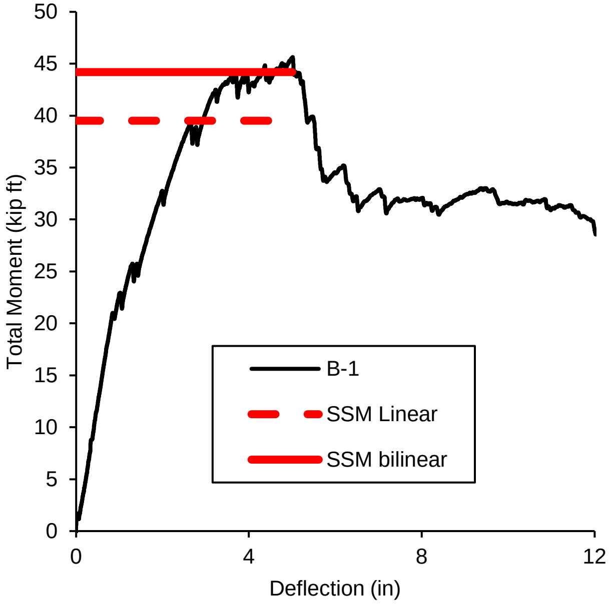
$$V_{n,h} = N * \sum F_i \leq A_s f_s$$

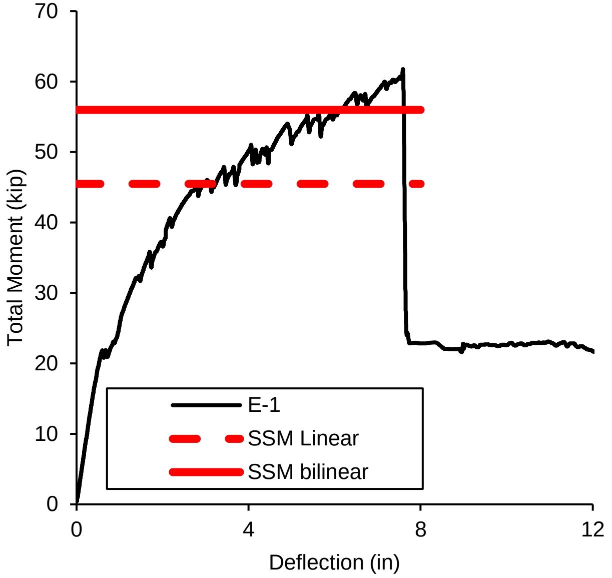


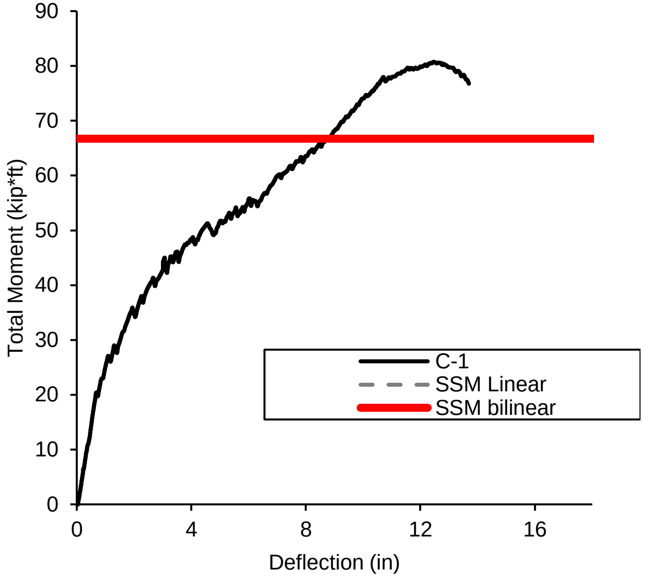
$$x_i = \begin{bmatrix} 6 \\ 30 \\ 54 \\ 78 \\ 102 \\ 126 \\ 150 \\ 174 \\ 198 \\ 222 \\ 240 \end{bmatrix} in \qquad \therefore \qquad \delta(i) = \delta_{max} * \frac{\left(\frac{l_c}{2} - x_i\right)}{\left(\frac{l_c}{2} - x_1\right)} = \begin{bmatrix} 0.056 \\ 0.055 \\ 0.044 \\ 0.039 \\ 0.033 \\ 0.027 \\ 0.021 \\ 0.016 \\ 0.01 \\ 0.004 \\ 0.0 \end{bmatrix} in$$

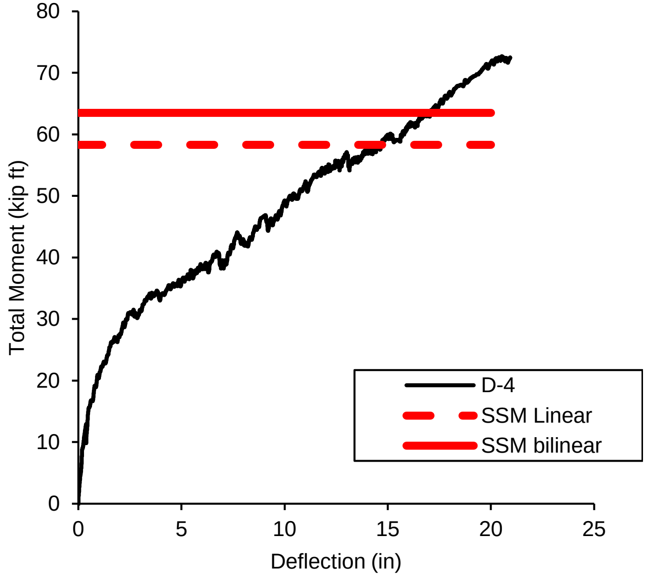
$$Force = Lookup\ \delta(i) = \begin{bmatrix} 9.41 \\ 8.68 \\ 7.95 \\ 7.23 \\ 6.5 \\ 5.77 \\ 5.05 \\ 4.32 \\ 2.92 \\ 1.25 \\ 0 \end{bmatrix} kip$$

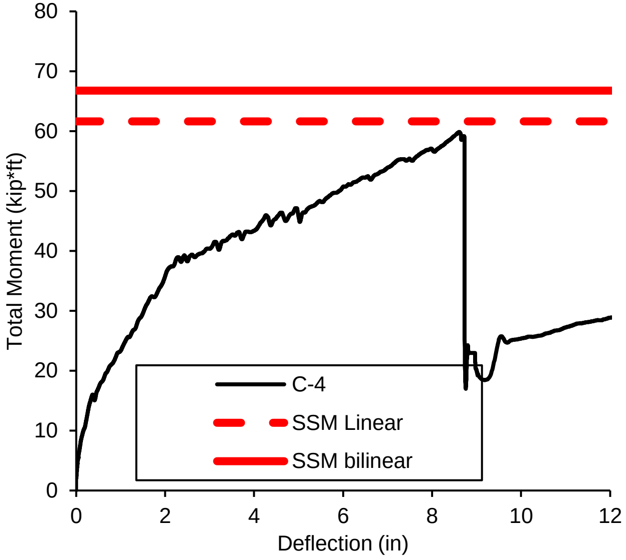
Shear slip method











CONCLUSIONS

- 17 insulated and 6 solid panels were tested
  - Different design conditions
  - Different failure modes
- Panels B1-3, E1-3, C4, D4 exhibited connector failure
- Panel A1-3, C1-3 and D1-3 exhibited steel yielding

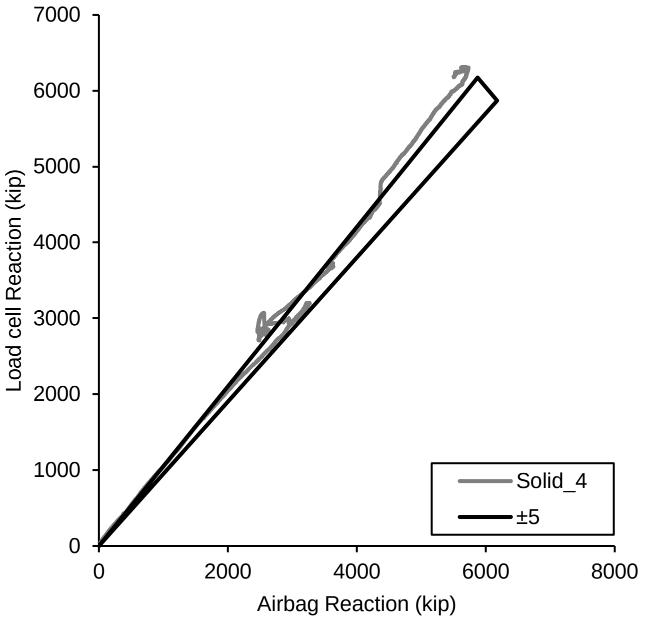
CONCLUSIONS

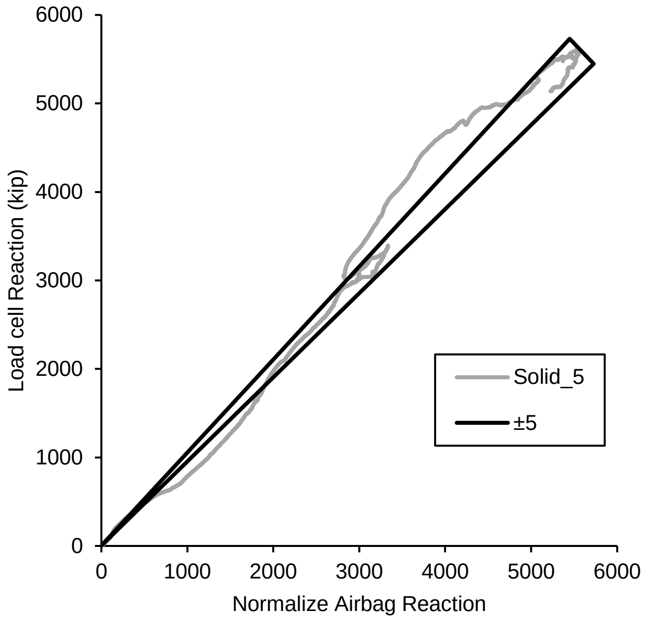
- Panel deformations and failure predicted well by the new methods for tilt-up composite walls.
- Two methods available to predict cracked panel deformations.
- Two methods available to predict connector failure.

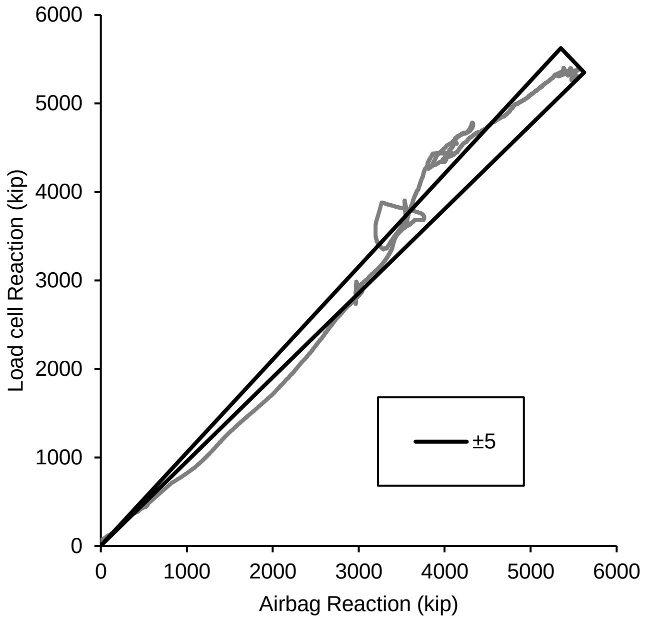
THANK YOU!

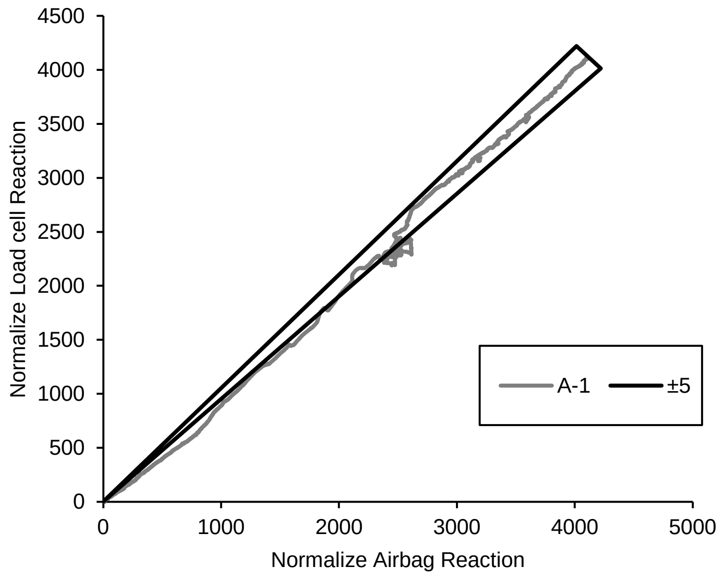
Questions?

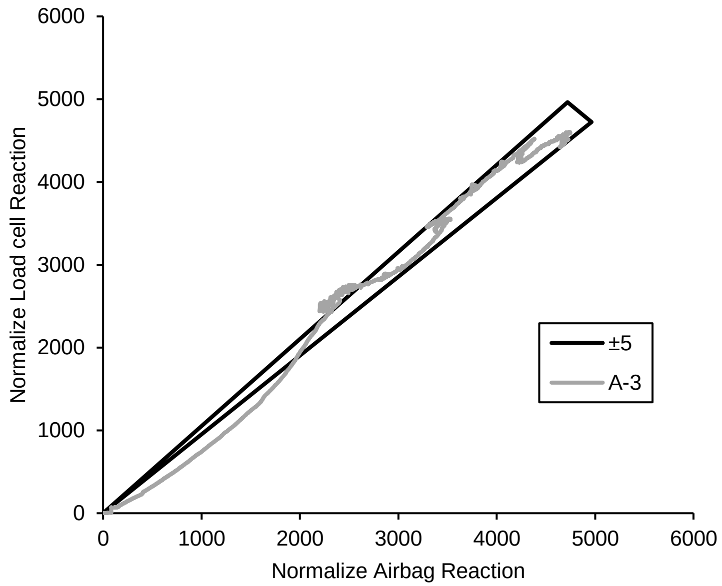
AIRBAG PRESSURE VS LOAD CELLS



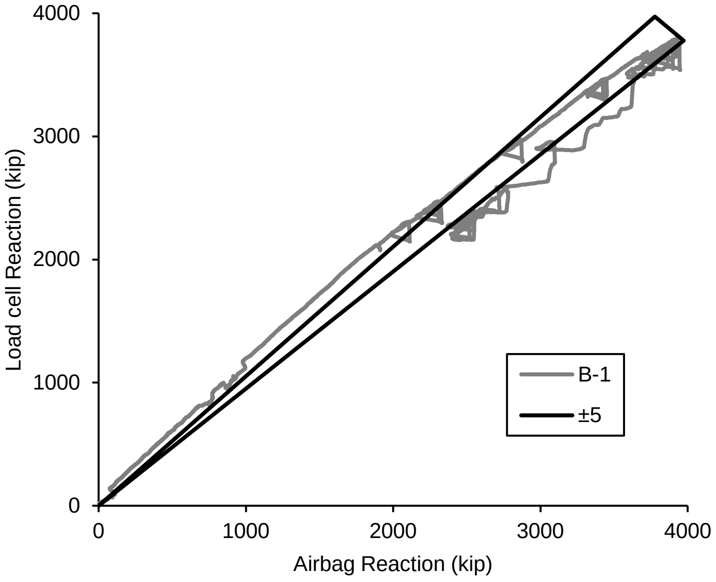


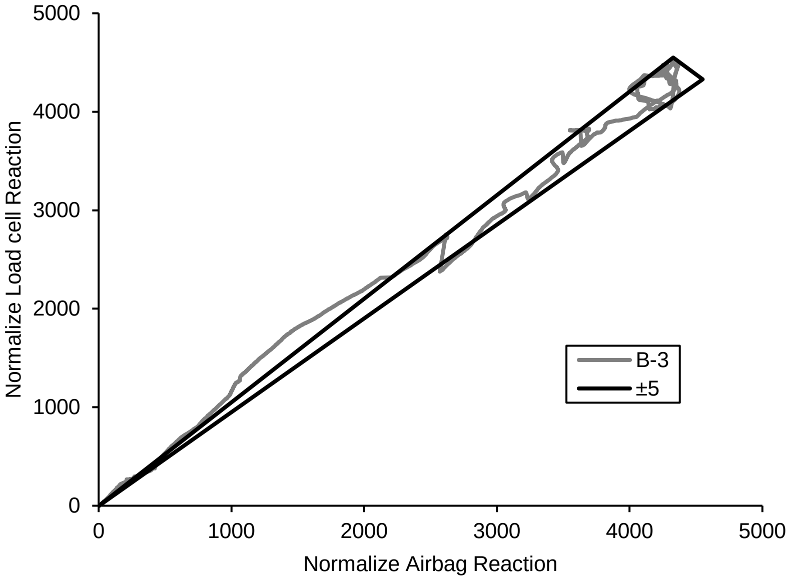


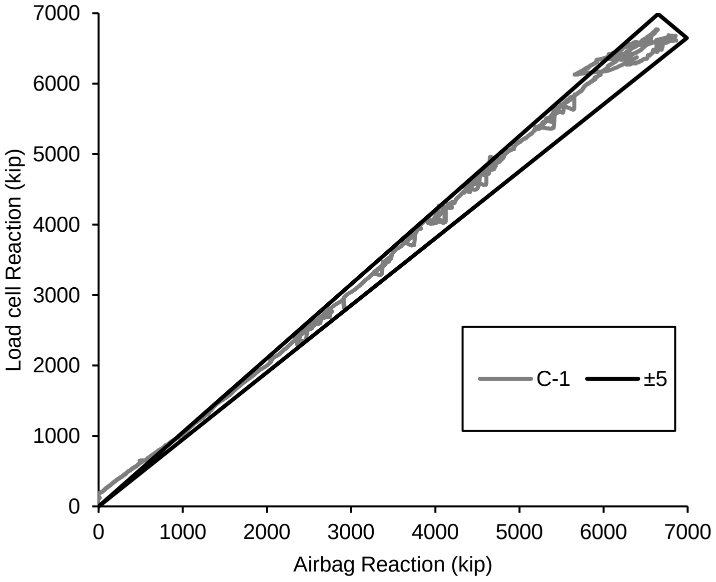


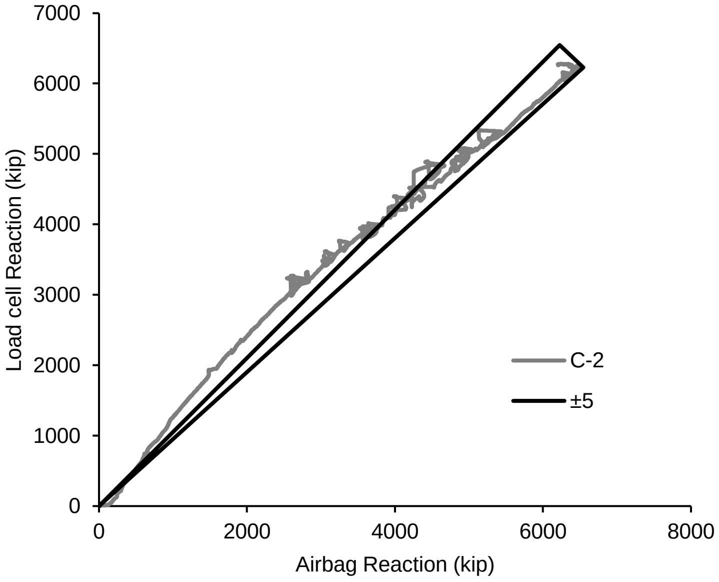


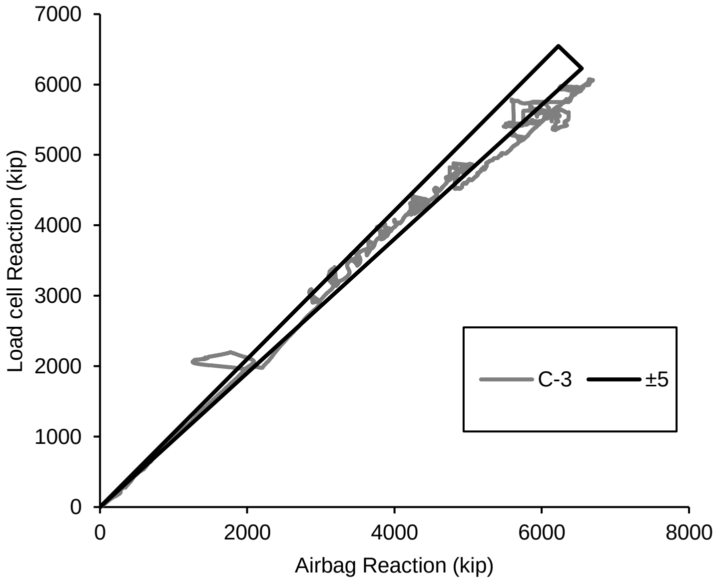
AIRBAG PRESSURE VS LOAD CELLS











AIRBAG PRESSURE VS LOAD CELLS